

Outline

- Ed4 Angular Distribution Models
- Cloud property differences between Ed2 and Ed4
- Flux differences due to changes in cloud properties and ADMs
- Separate Terra/Aqua ADM or combined Terra+Aqua ADM
- Validation: shortwave direct integration

Normalize predicted and observed radiance

$$\left. \begin{aligned} R(\theta_0, \theta, \phi) &= \frac{\pi \hat{I}(\theta_0, \theta, \phi)}{\hat{F}(\theta_0)} \\ F(\theta_0) &= \frac{\pi I_o(\theta_0, \theta, \phi)}{R(\theta_0, \theta, \phi)} \end{aligned} \right\} F(\theta_0) = \frac{I_o(\theta_0, \theta, \phi)}{\hat{I}(\theta_0, \theta, \phi)} \hat{F}(\theta_0)$$

Observed radiance:

$$I_j^o, \quad j = 1, \dots, n$$

$$\bar{I}^o = \frac{1}{n} \sum_{j=1}^n I_j^o \quad \bar{\hat{I}} = \frac{1}{n} \sum_{j=1}^n \hat{I}_j$$

Predicted radiance:

$$\hat{I}_j, \quad j = 1, \dots, n$$

$$RMS = \sqrt{\frac{1}{n} \sum_{j=1}^n \left(\frac{\hat{I}_j}{\bar{\hat{I}}} - \frac{I_j^o}{\bar{I}^o} \right)^2}$$

1°

- RMS error between normalized predicted radiance and normalized observed radiance is used to assess the ADM error

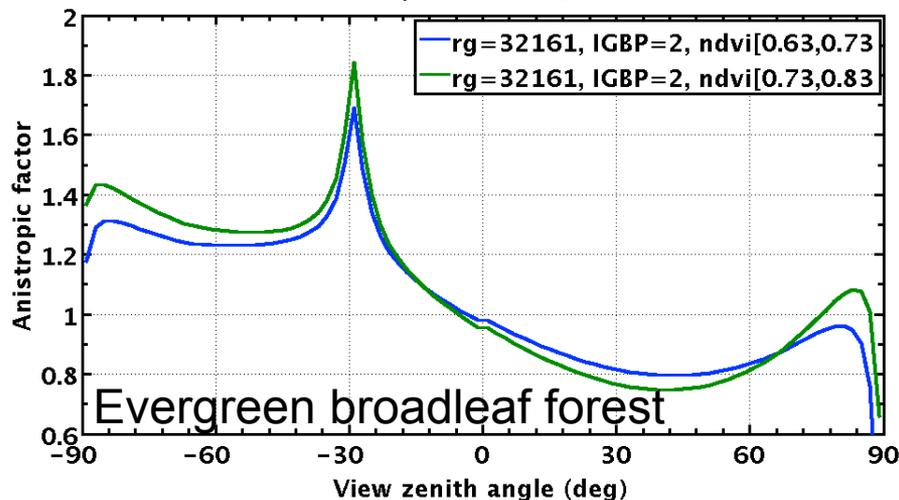
SW angular distribution model over clear land: Modified RossLi

- Collect clear-sky reflectance over $1^\circ \times 1^\circ$ regions for every calendar month;
- Stratify reflectance within each $1^\circ \times 1^\circ$ region by NDVI (0.1) and $\cos\theta_0$ (0.2);
- Apply modified RossLi fit to produce BRDF and ADM for each NDVI and $\cos\theta_0$ intervals within each $1^\circ \times 1^\circ$ region.

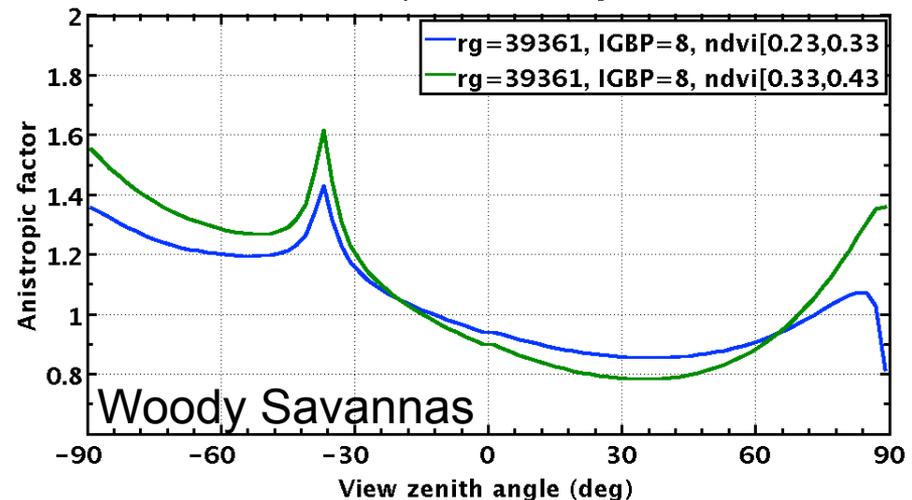
$$\rho(\mu_0, \mu, \phi) = k_0 + k_1 \cdot B_1(\mu_0, \mu, \phi) + k_2 \cdot B_2(\mu_0, \mu, \phi)$$

from Maignan et al., 2004

PP Anisotropic factor for Jan SZA=28



PP Anisotropic factor for Aug SZA=36

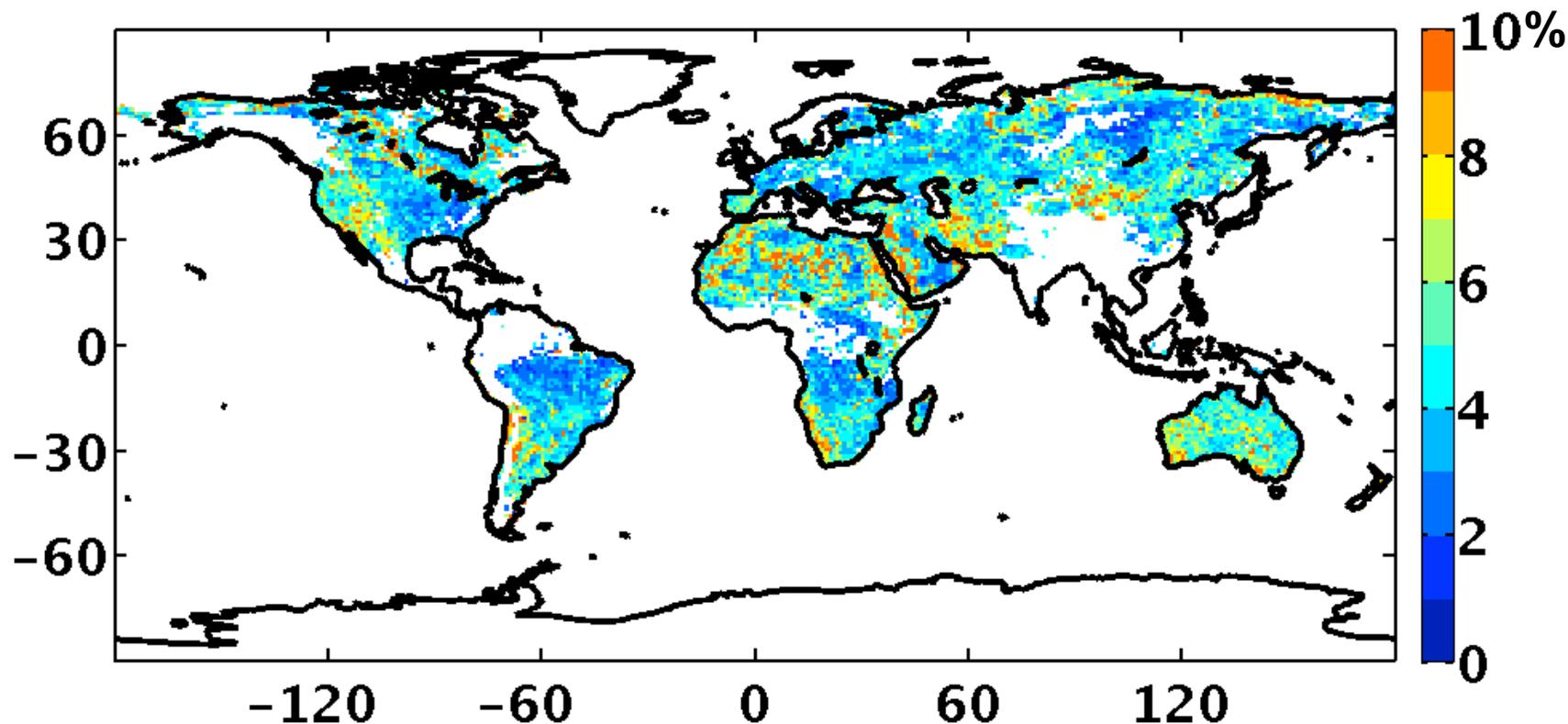


Ed4 clear land ADM reduces the RMS error

- Apply Ed4 ADM to Ed4 SSF

$$RMS = \sqrt{\frac{1}{n} \sum_{j=1}^n \left(\frac{\hat{I}_j}{\hat{I}} - \frac{I_j^o}{I^o} \right)^2}$$

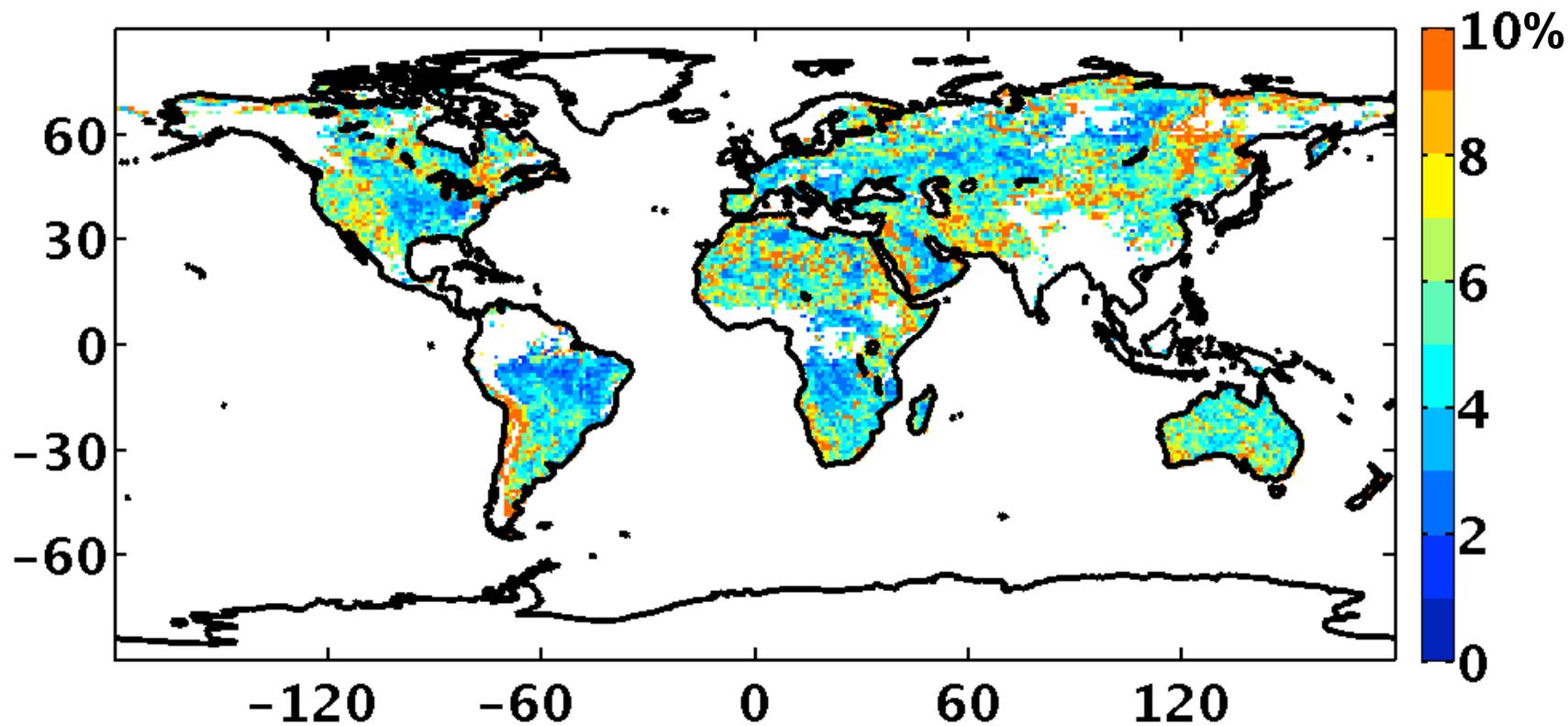
200207:Terra-FM1 ClrLnd Ed4SSF/Ed4ADM: mean RMS=5.8%



Ed4 clear land ADM reduces the RMS error

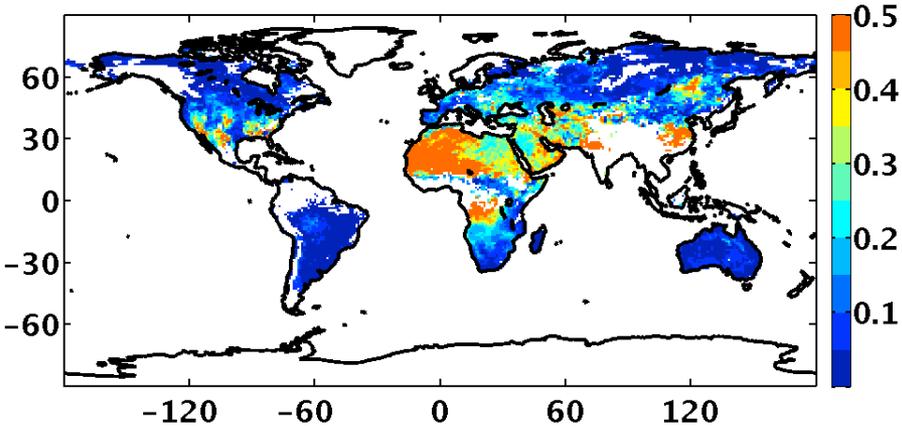
- Apply Ed2 ADM to Ed3 SSF

200207:Terra-FM1 ClrLnd Ed3SSF/Ed2ADM: mean RMS=7.9%

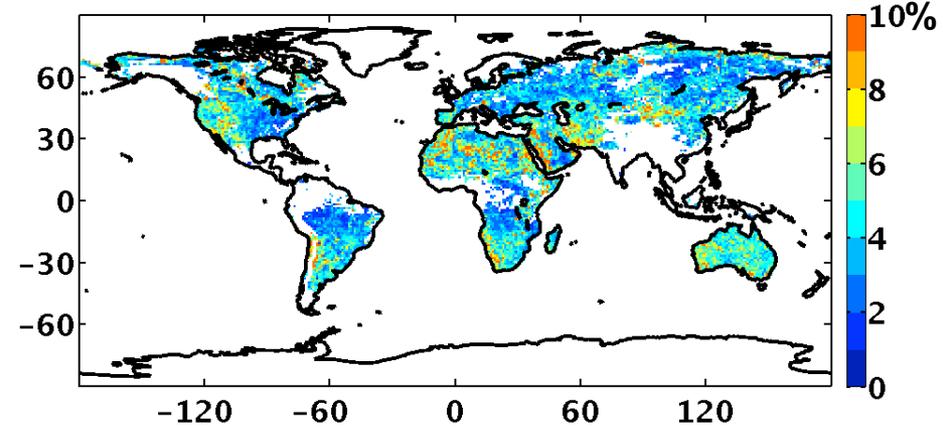


RMS error as a function of AOD

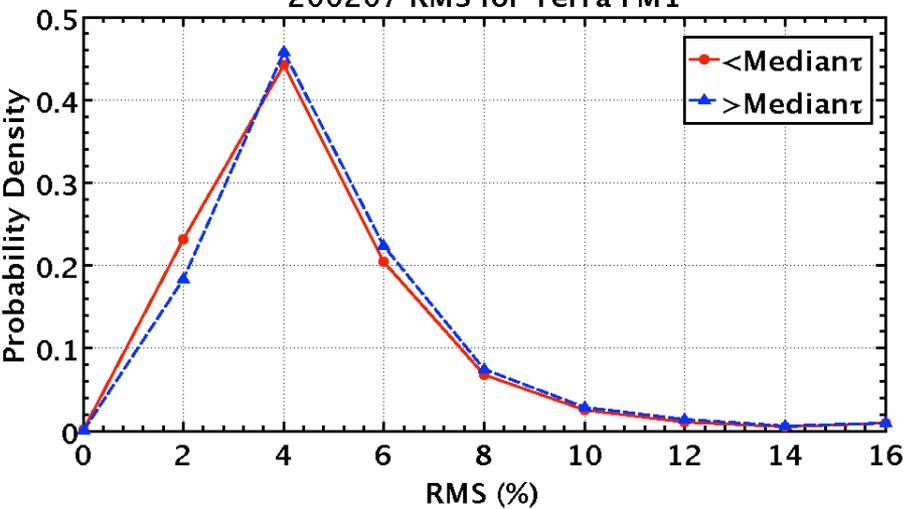
200207 Median AOD Terra FM1



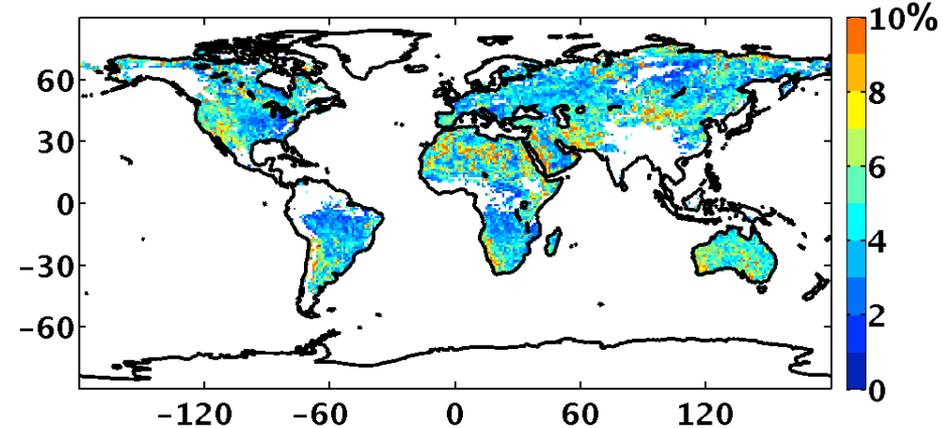
200207 ClrLnd Ed4ADM Terra FM1 AOD < med: mean RMS=5.4%



200207 RMS for Terra FM1



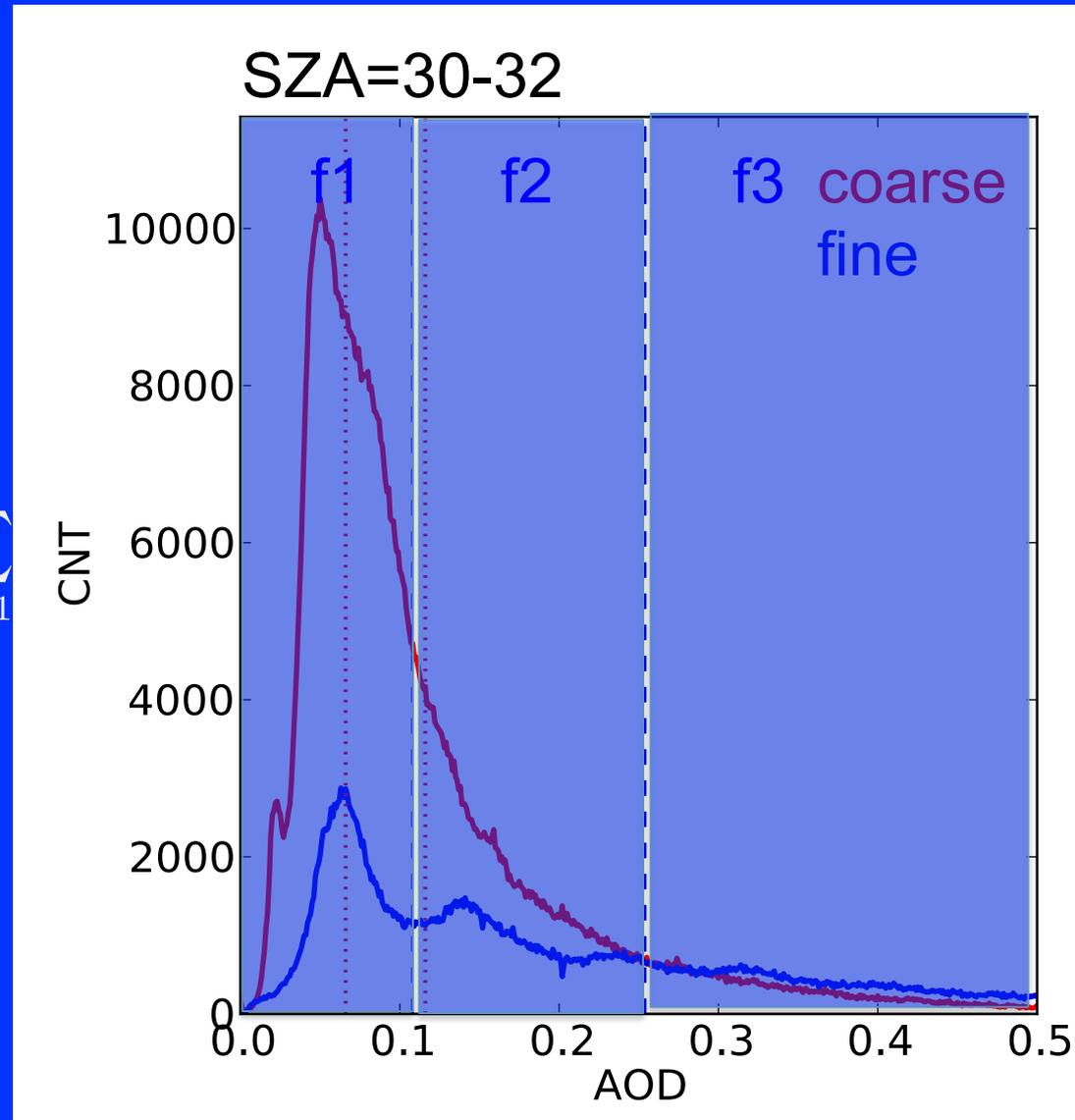
200207 ClrLnd Ed4ADM Terra FM1 AOD > med: mean RMS=5.6%



Ed4ADM over clear ocean accounts for aerosol loading and type

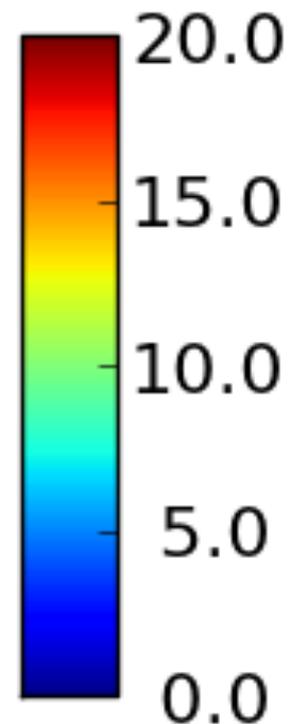
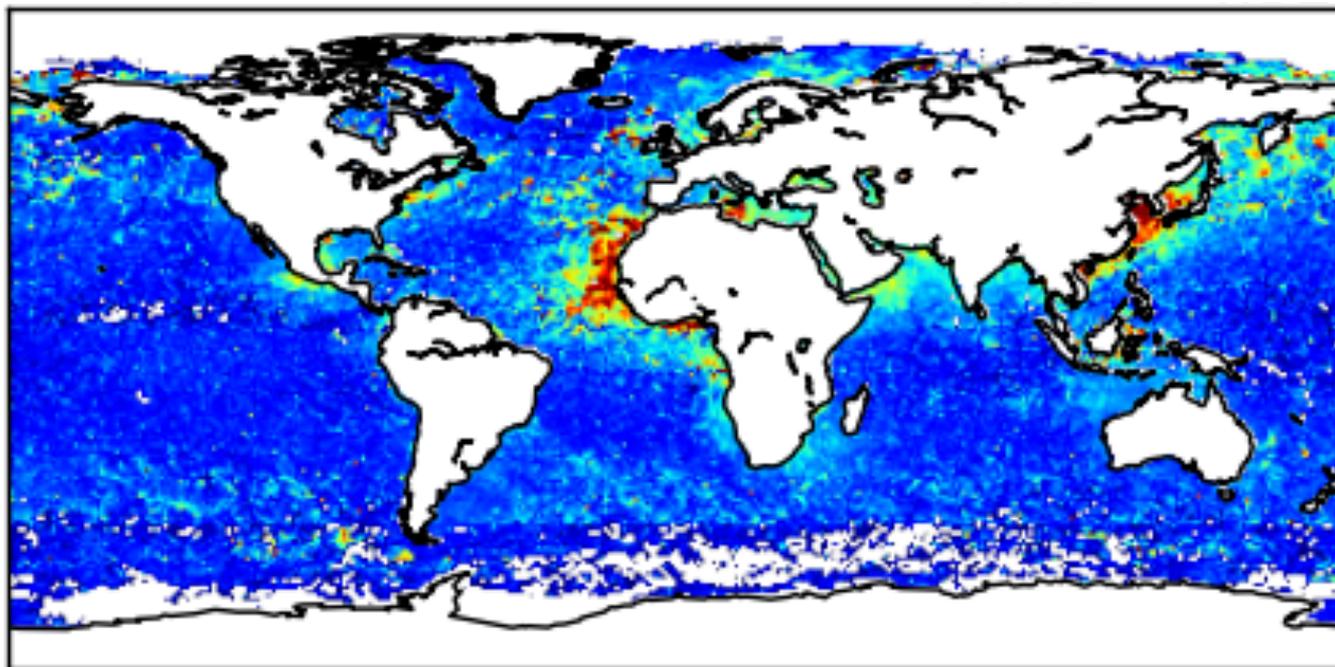
- AOD retrieval based upon a fine-mode aerosol look-up table (urban) and a coarse-mode aerosol look up table (maritime);
- Stratify fine-mode aerosols into 3 AOD bins and coarse-mode aerosols into 3 AOD bins;
- Build ADM for each AOD bin and type separately (6 ADMs).

$$\epsilon_c = \sum_{j=1}^6$$



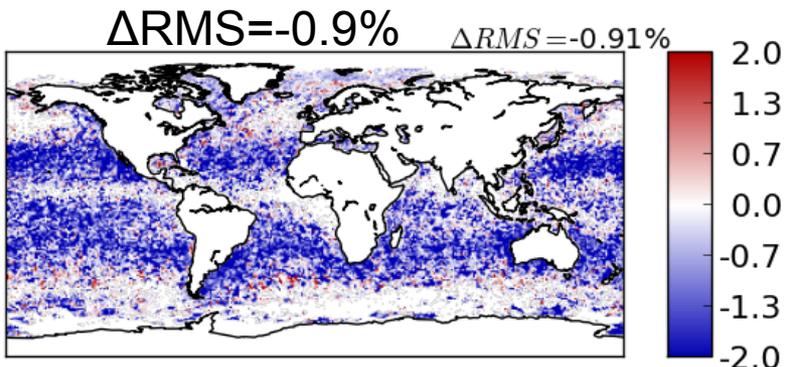
Ed4ADM reduces the RMS error over clear ocean

Clear ocean with AOD retrieval 2002 Ed4SSF/Ed4ADM: RMS =4.3%

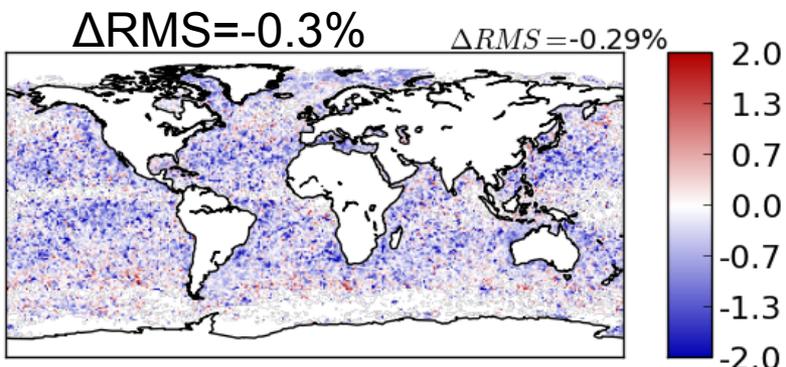


RMS error increases for the largest coarse mode AOD bin

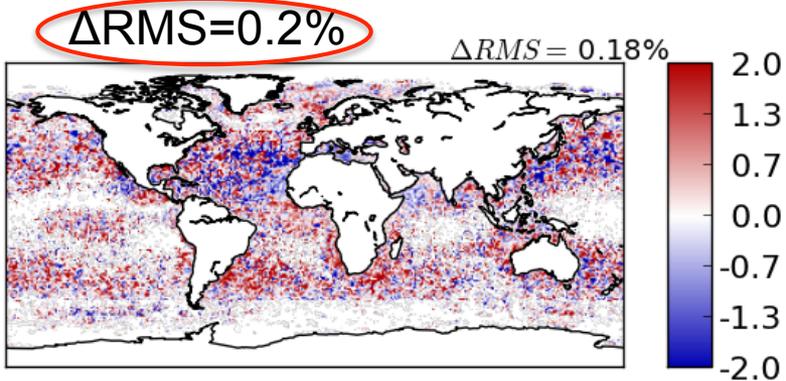
coarse-mode-like fine-mode-like



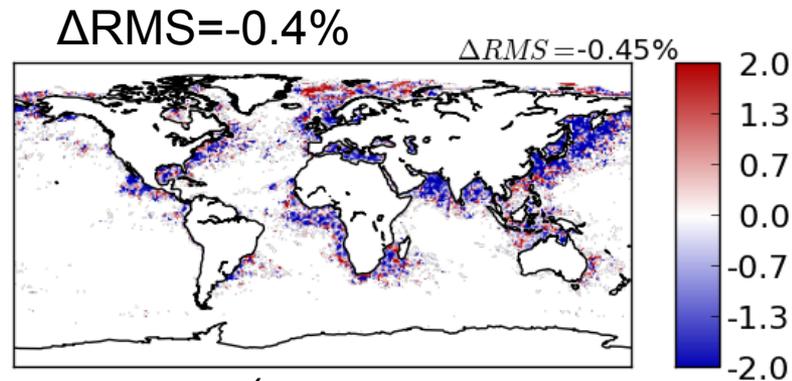
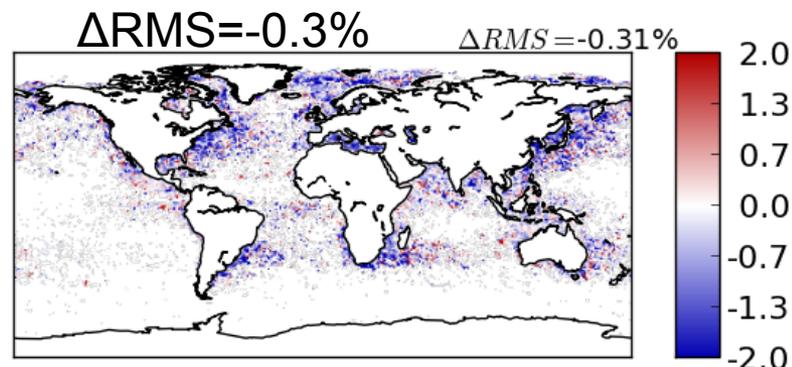
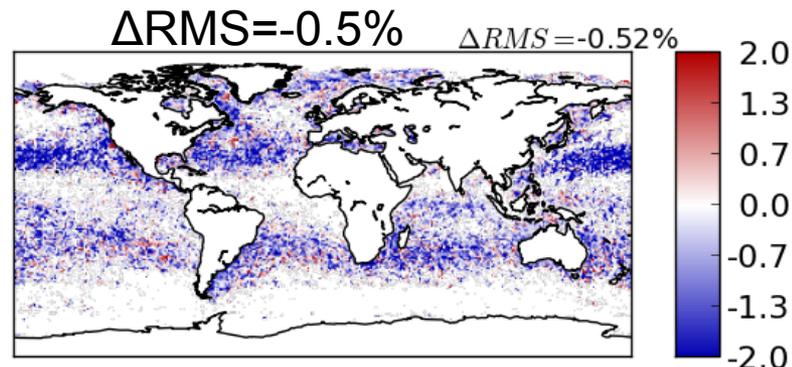
0-33%



33-66%



66-100%

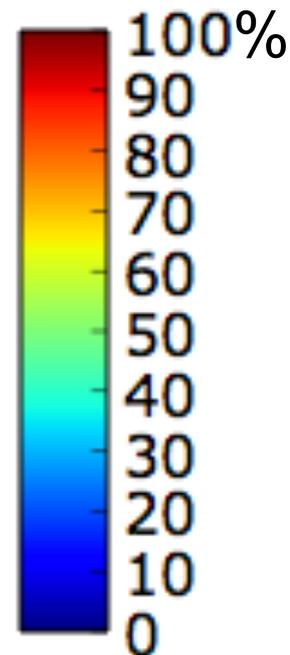
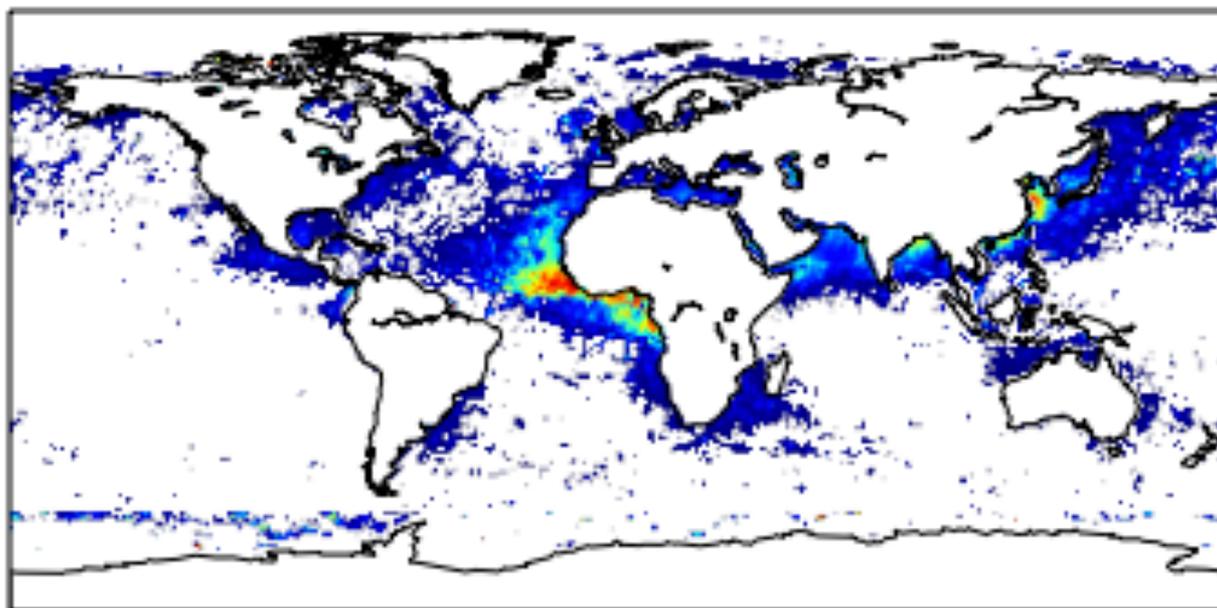


(Terra 2002 cross-track)

Is the largest coarse mode AOD bin contaminated by clouds?

- Use cloud mask clear_Strong percentage to eliminate footprints that are possibly contaminated by clouds

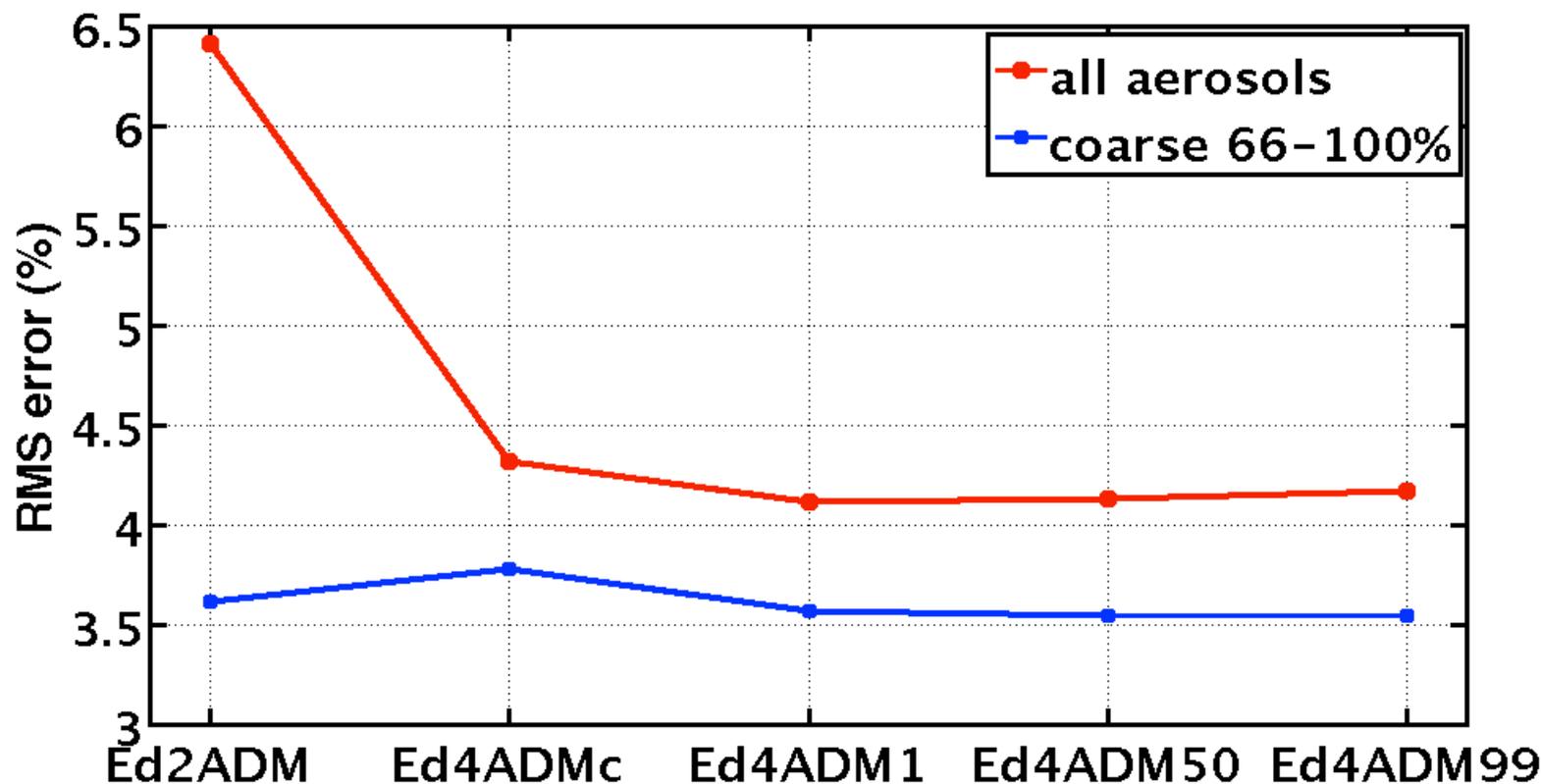
% of samples with Clr_strong < 1%



Develop clear-ocean ADM excluding questionable clear FOVs

- Ed4ADM_c: including all clear FOVs;
- **Ed4ADM₁**: excluding clear FOVs with $\text{clear_strong} < 1\%$;
- Ed4ADM₅₀: excluding clear FOVs with $\text{clear_strong} < 50\%$;
- Ed4ADM₉₉: excluding clear FOVs with $\text{clear_strong} < 99\%$;

RMS error over clear ocean for Terra FM1 2002



Angular distribution model over cloudy ocean

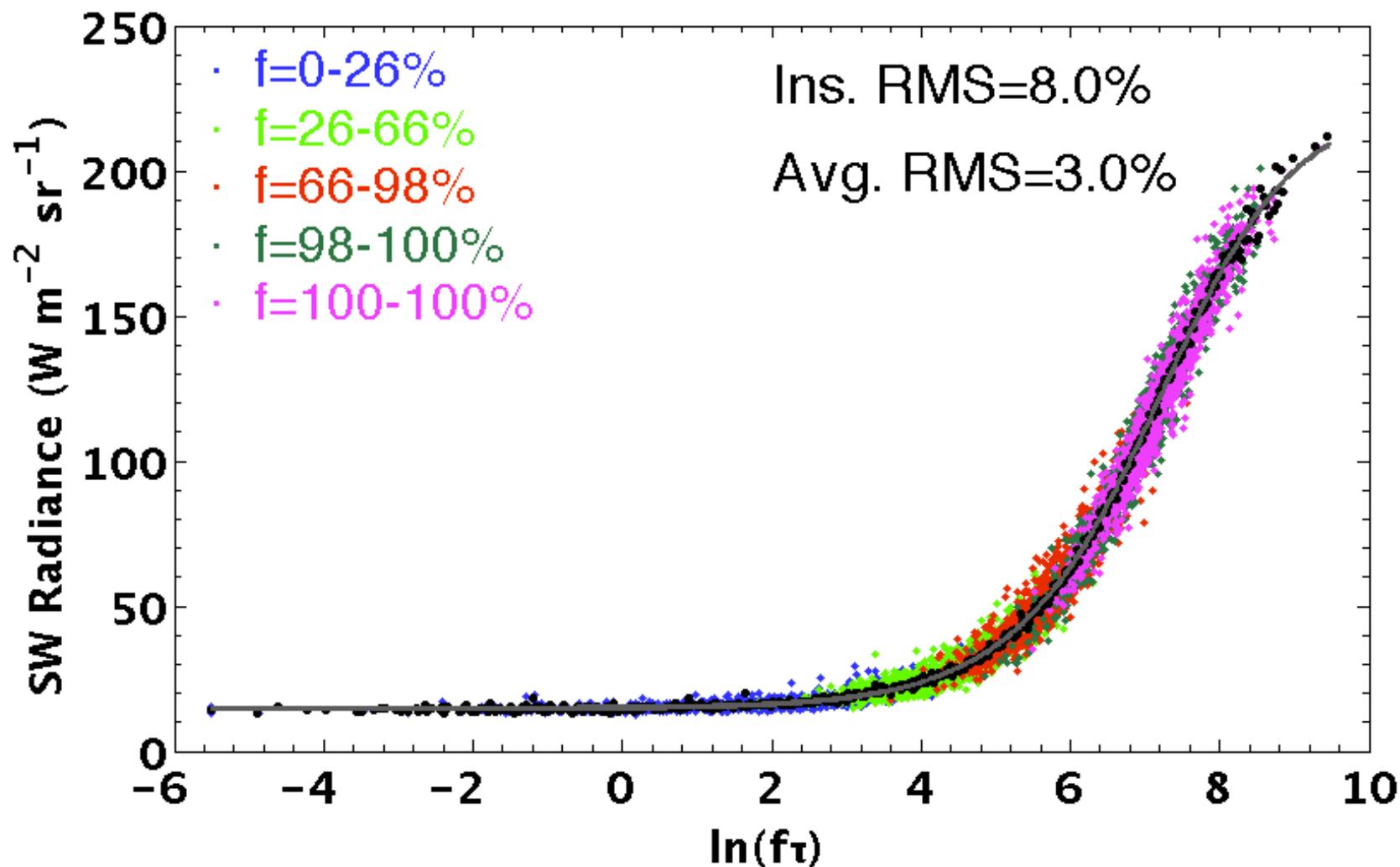
- For glint angle $> 20^\circ$, or glint angle $< 20^\circ$ and $\ln(f\tau) > 6$:
 - Average instantaneous radiances into 775 intervals of $\ln(f\tau)$ for each angular bin (2°) separately for liquid, mixed, and ice clouds;
 - Apply a five-parameter sigmoidal fit to mean radiance and $\ln(f\tau)$;

$$I = I_0 + \frac{a}{[1 + e^{-(x-x_0)/b}]^c}$$

- For glint angle $< 20^\circ$ and $\ln(f\tau) < 6$:
 - Calculate mean radiance for 6 wind speed bins and 4 $\ln(f\tau)$ bins;
 - Use mean radiance to build ADM

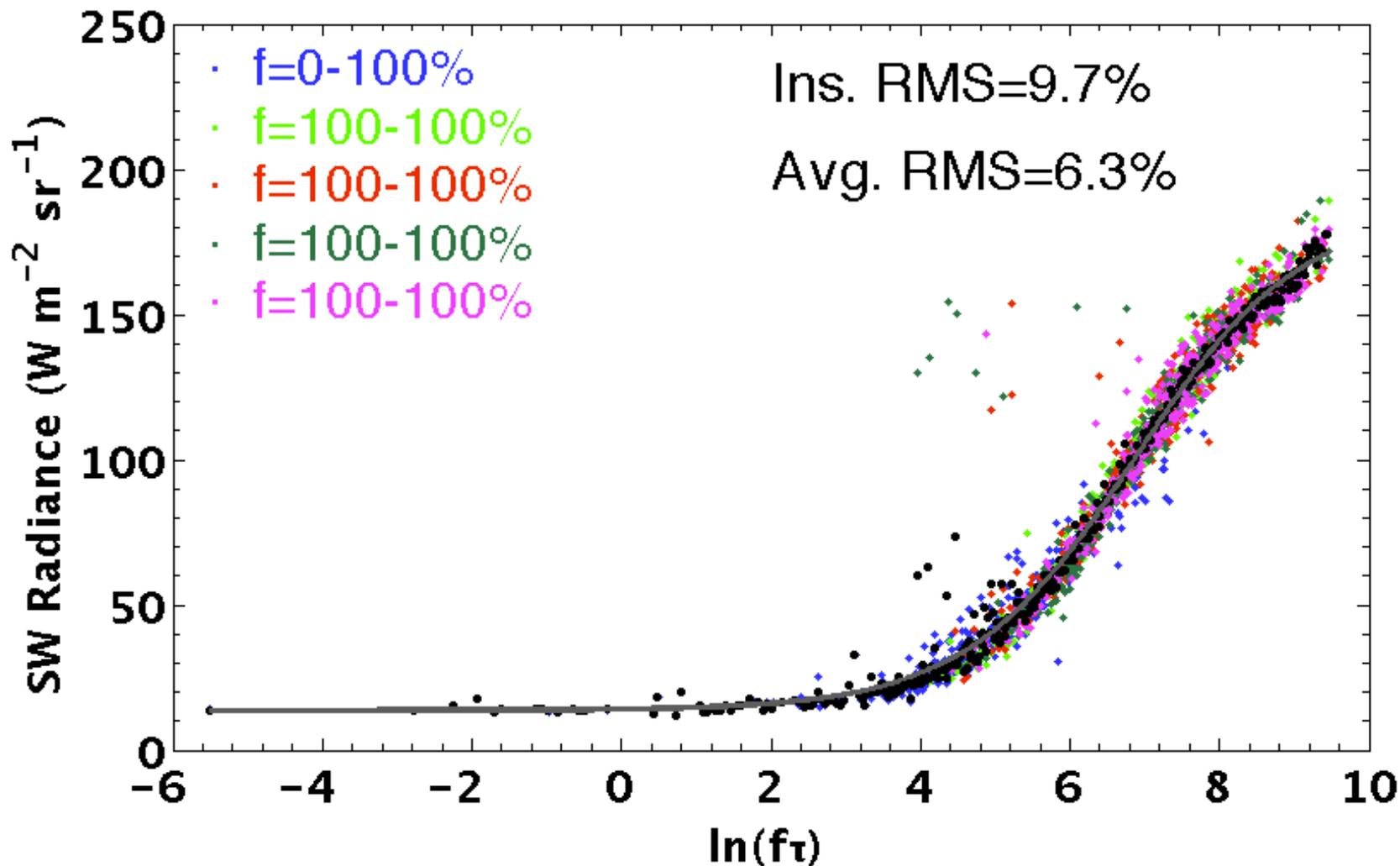
Ed4SSF produces tighter sigmoidal fit over ocean: liquid

Terra Ed4 liquid cloud: SZA[45], VZA[19], RAZ[89]



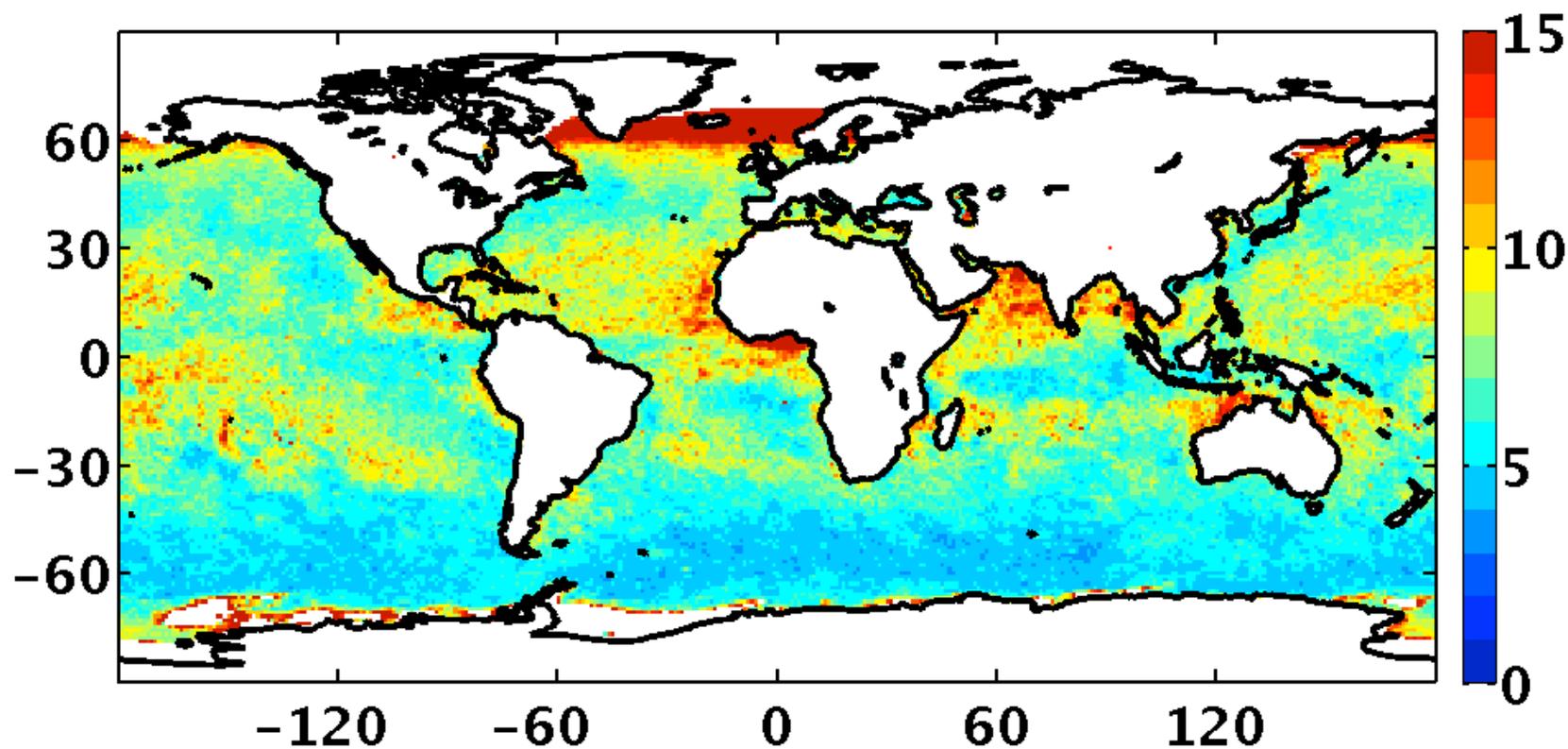
Ed4SSF produces tighter sigmoidal fit over ocean: ice

Terra Ed2 ice cloud: SZA[55], VZA[15], RAZ[177]



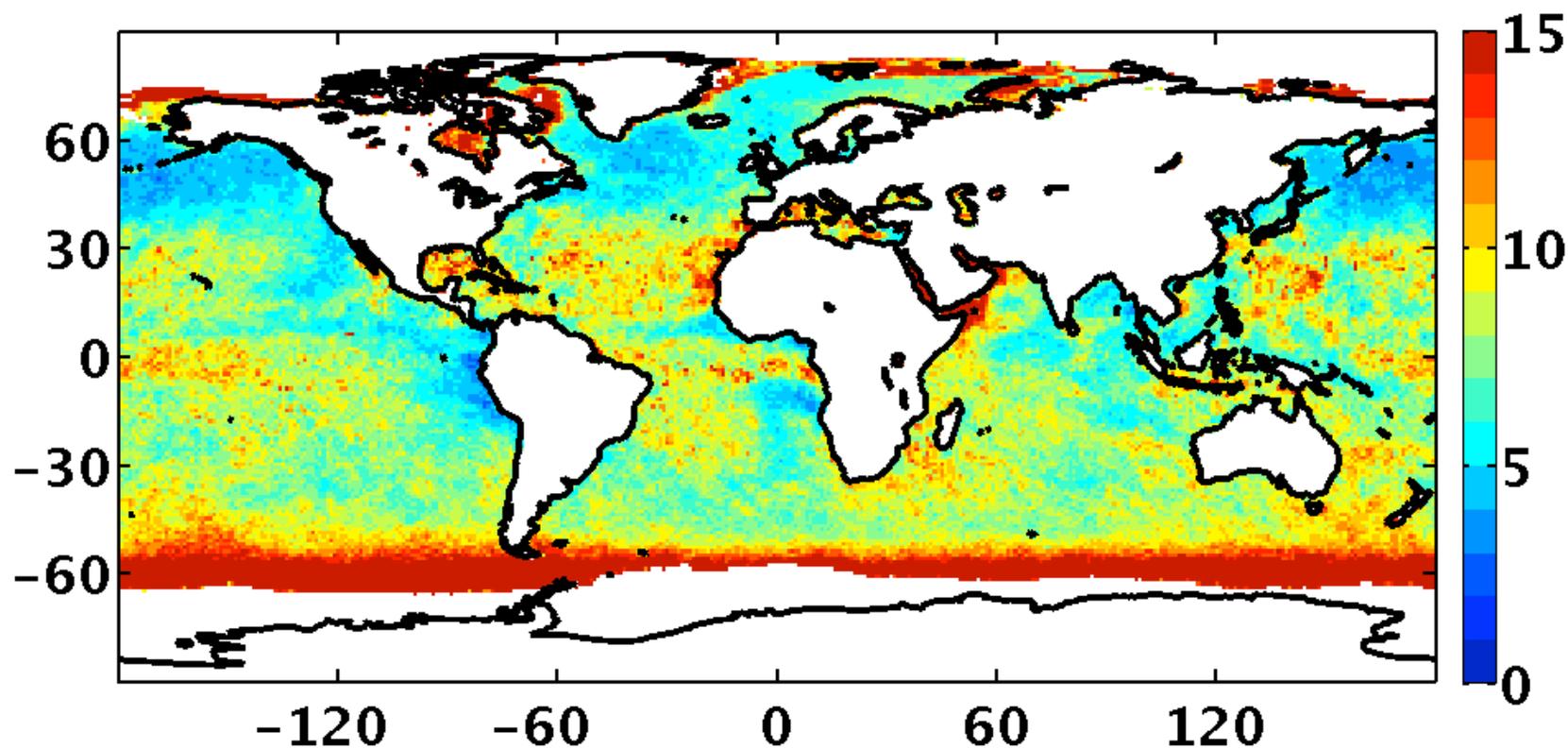
Ed4 ADM decreases the RMS error over cloudy ocean: Terra FM1

200201:Terra-FM1 CldOce Ed4ADM: mean RMS=8.0%



Ed4 ADM decreases the RMS error over cloudy ocean: Aqua FM4

200407:Aqua-FM4 CldOce Ed4ADM: mean RMS=10.1%



Angular distribution model over cloudy land/desert

- Derive cloudy area contribution from observed radiance:

$$f I^{cld}(\mu_0, \mu, \phi) = I(\mu_0, \mu, \phi) - (1 - f) \frac{\mu_0 E_0}{\pi} \rho^{clr}(\mu_0, \mu, \phi) - f \frac{\mu_0 E_0}{\pi} \left[\rho^{clr}(\mu_0, \mu, \phi) e^{\frac{-\tau}{\mu_0}} e^{\frac{-\tau}{\mu}} + \bar{\alpha}^{clr} \frac{t^{cld}(\tau, \mu_0) t^{cld}(\tau, \mu)}{1 - \bar{\alpha}^{clr} \bar{\alpha}^{cld}(\tau)} \right]$$

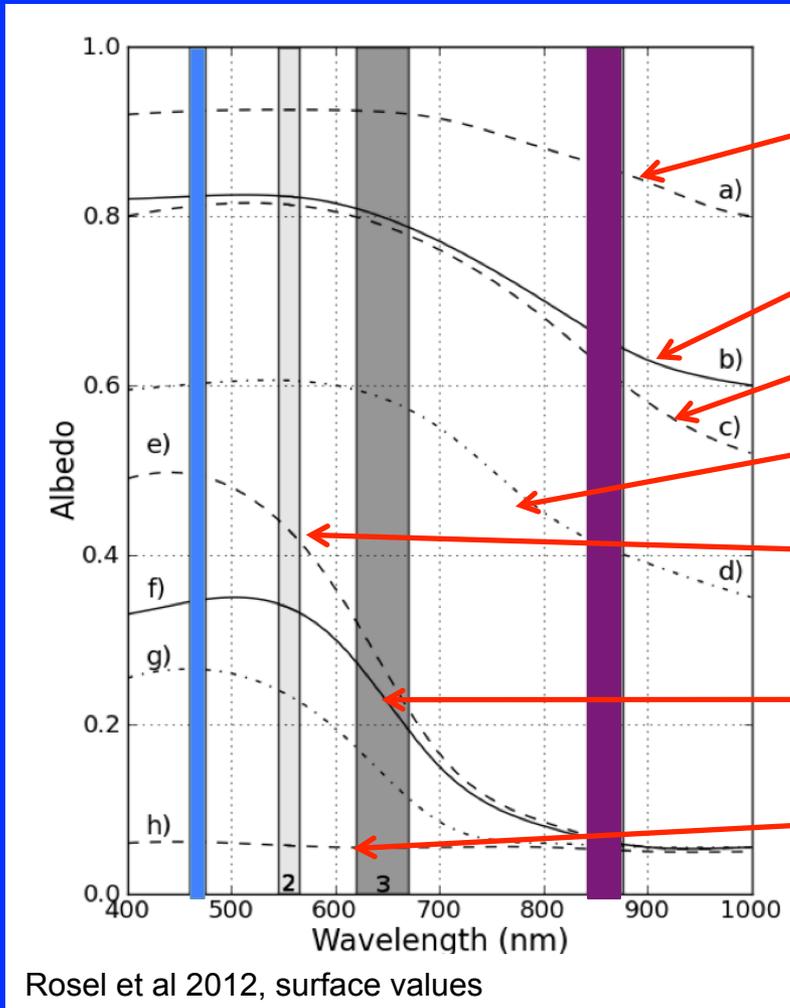
- Average instantaneous $f I^{cld}$ into 380 intervals of $\ln(f \tau)$ for each angular bin (5°) for three cloud phases;
- Apply a five-parameter sigmoidal fit to mean $f I^{cld}$ and $\ln(f \tau)$;

$$I = I_0 + \frac{a}{[1 + e^{-(x-x_0)/b}]^c}$$

- Ed4 ADM reduces the RMS error over cloudy land.

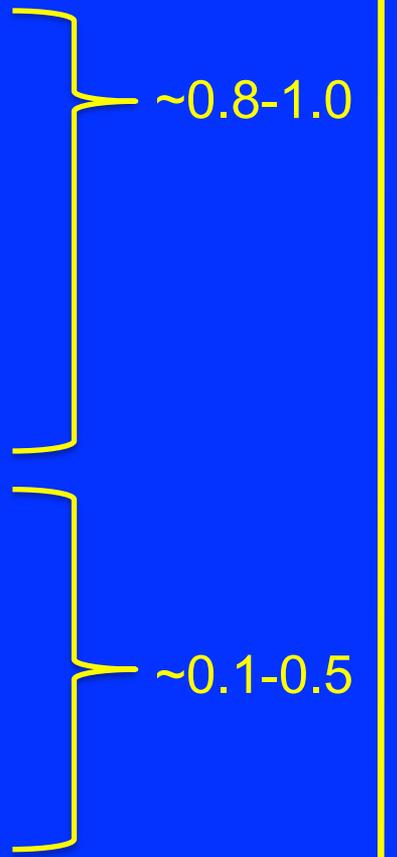
Sea ice index to quantify the brightness of sea ice surface

$$\eta = 1 - \frac{\rho_{0.47} - \rho_{0.86}}{\rho_{0.47} + \rho_{0.86}}$$



- Snow
- Bare ice
- Wet snow
- Melting first year ice
- Young melting pond
- Melting ponds
- Open water

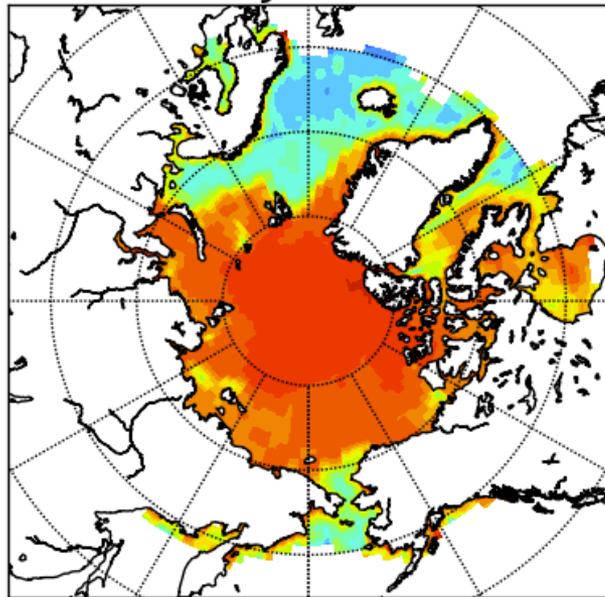
High sea ice index



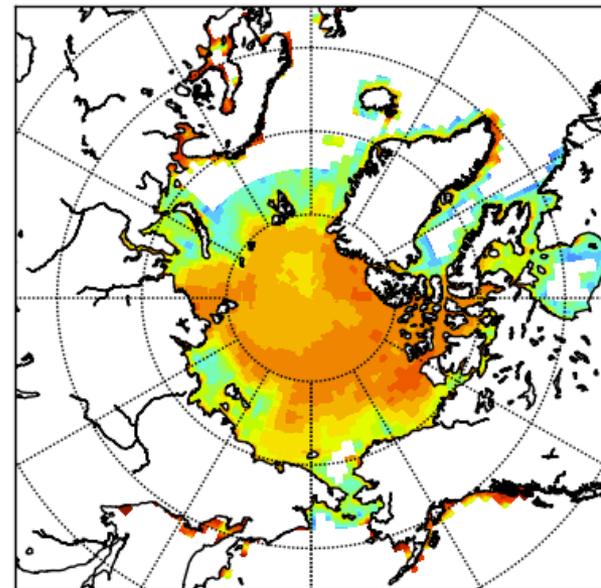
Low sea ice index

Sea ice index decreases as ice starts melting

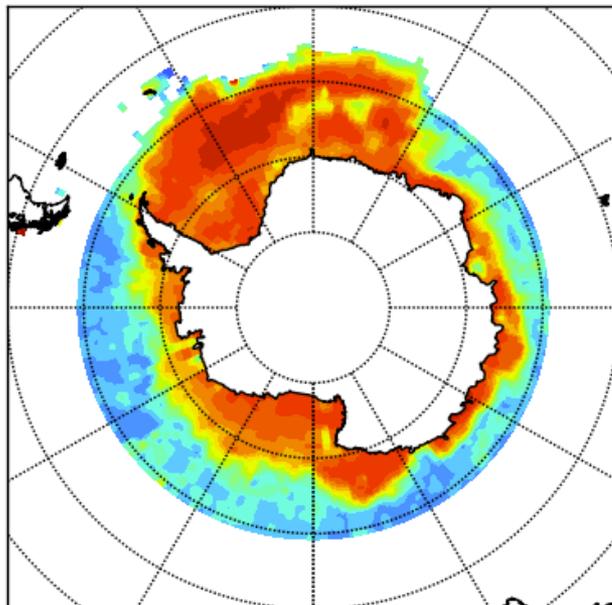
terra JUN 2003



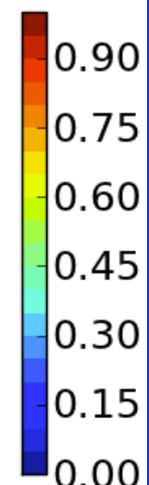
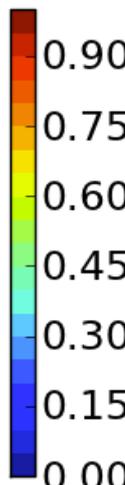
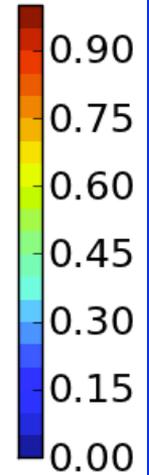
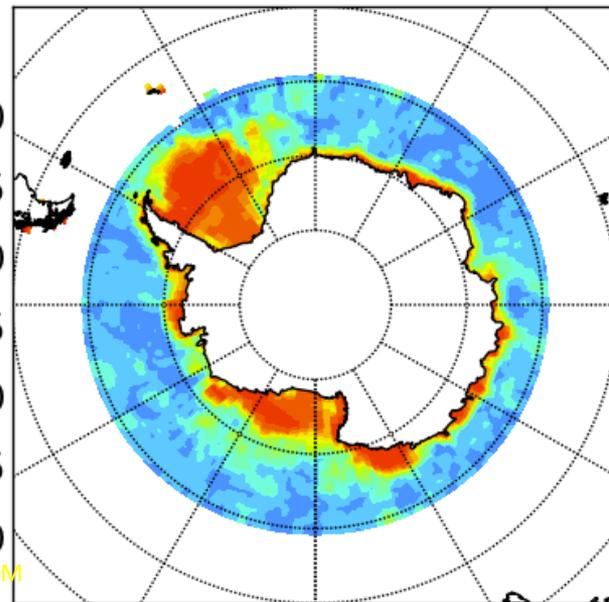
terra AUG 2003



terra DEC 2002



terra FEB 2003



CERES STM

Shortwave Ed4ADMs over sea ice

- Clear-sky
 - 6 sea ice fraction bins
 - 3 sea ice index bins for scenes with sea ice fraction >99%
- Partly cloudy
 - 4 cloud fraction bins
 - 2 $\ln(\tau)$ bins
 - 6 sea ice fraction bins
 - 3 sea ice index bins for scenes with sea ice fraction >99%
- Overcast
 - Linear fit between mean reflectance and $\ln(\tau)$, separately for liquid and ice clouds and 5 sea ice index ranges derived from monthly maps

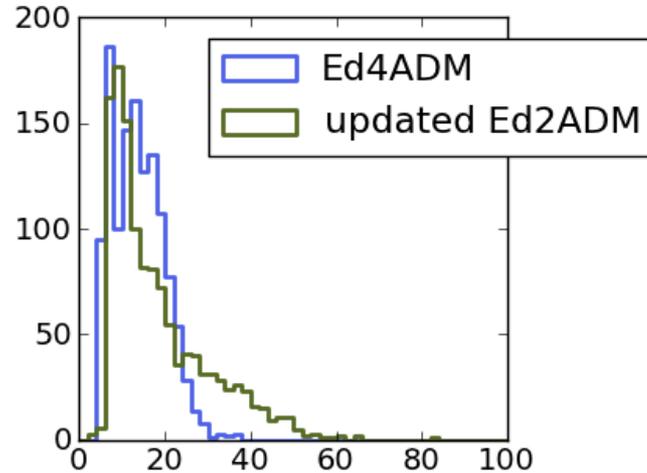
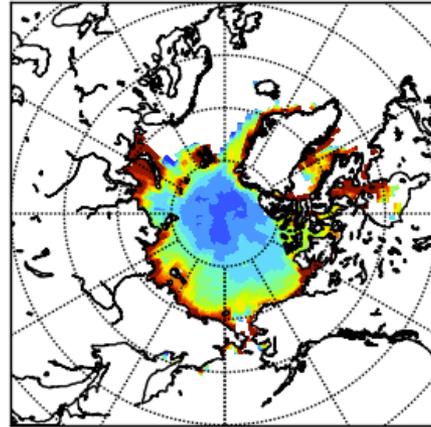
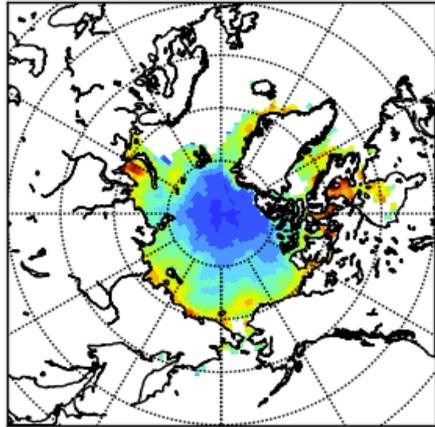
RMS error for sea ice

Ed4SSF (with Ed4ADM) Ed4SSF (with updated Ed2ADM)

July 2003 all-sky

$\mu = 13.71\%$

$\mu = 18.48\%$

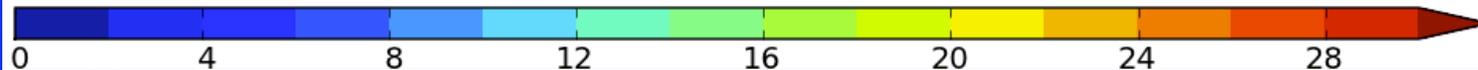
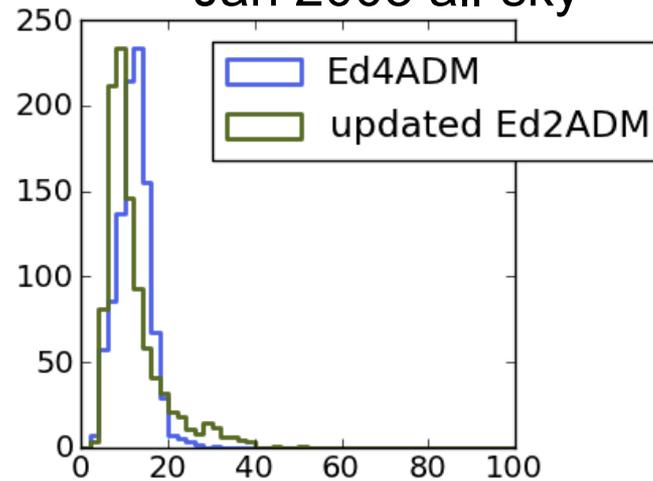
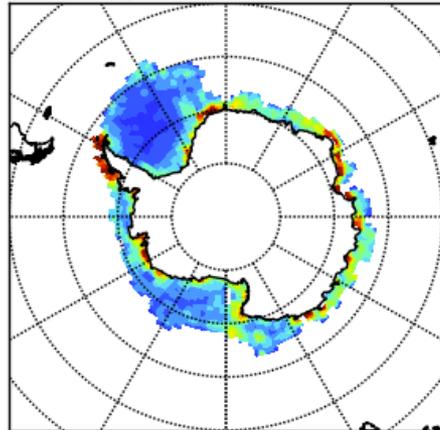
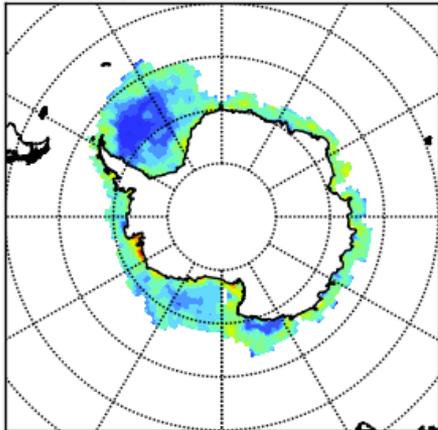


Ed4SSF (with Ed4ADM) Ed4SSF (with updated Ed2ADM)

Jan 2003 all-sky

$\mu = 11.92\%$

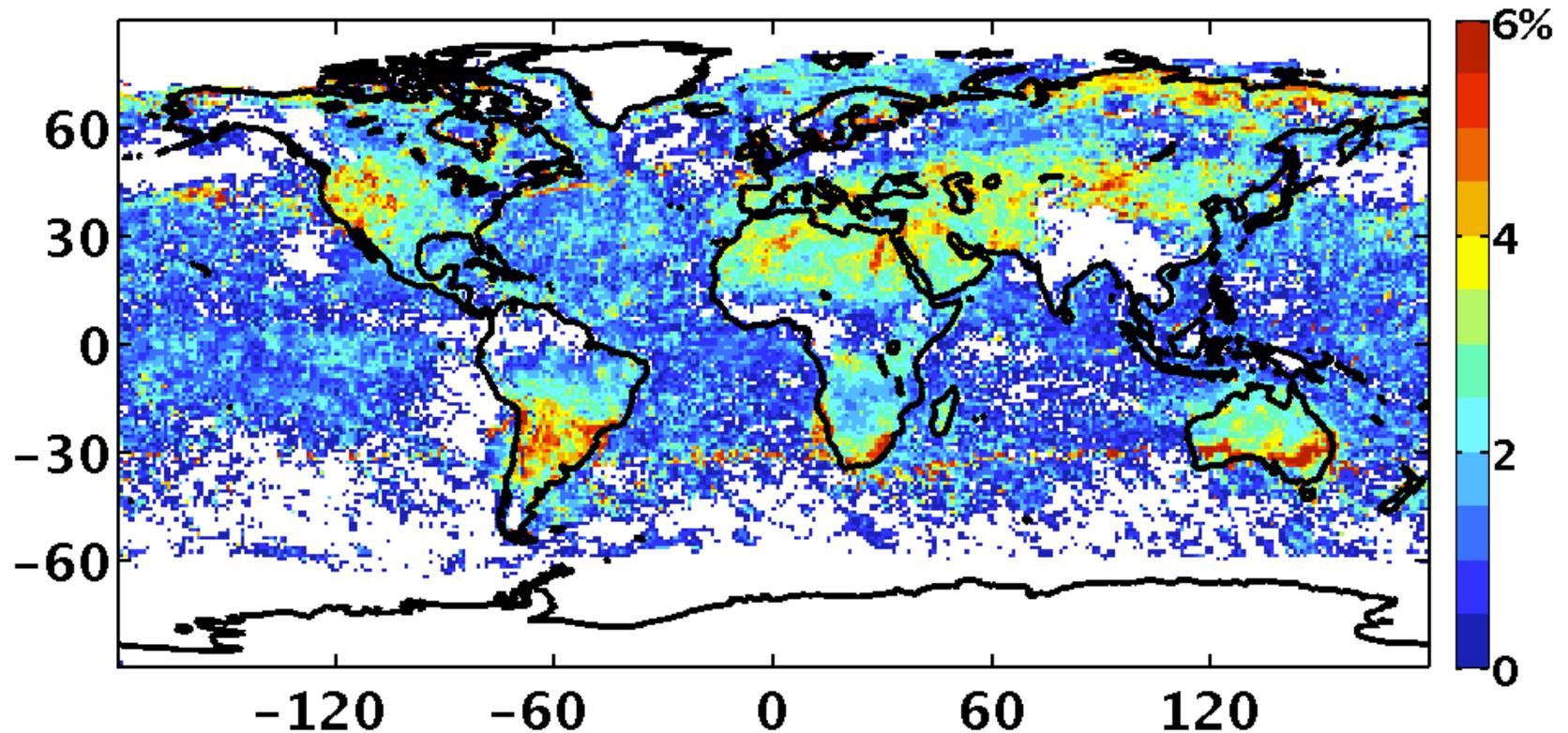
$\mu = 11.83\%$



Clear-sky longwave/window angular distribution models

- Over clear land/ocean/snow/ice:
 - Ed4 ADMs increased the surface skin temperature (T_s) bins and interpolation between the T_s bins;

200007: Terra clr day Ed2ADM: RMS=2.2%



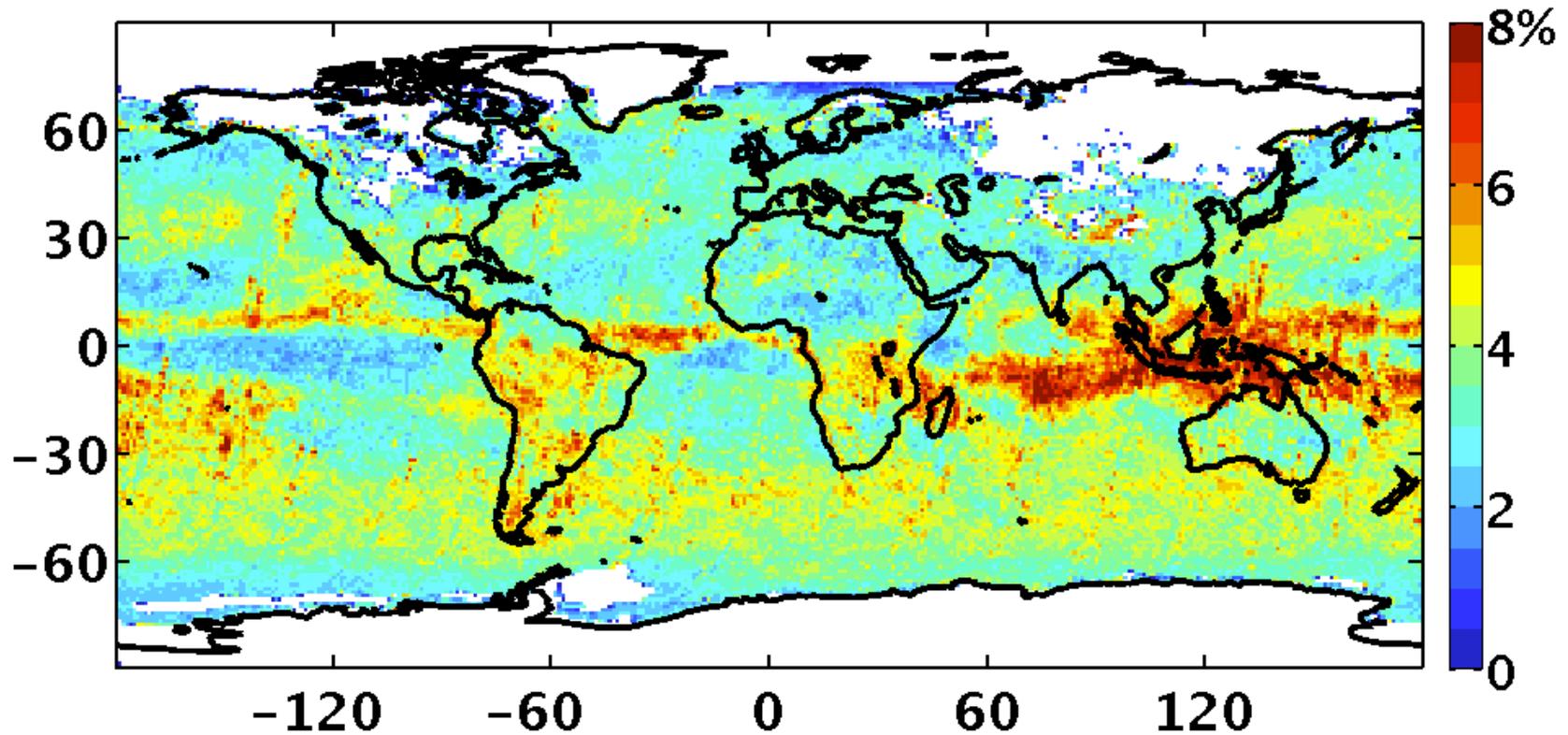
Cloudy-sky LW/WN angular distribution models

- Ed2 ADM uses third-order polynomial fits between radiance and 'pseudoradiance' (Ψ) to determine anisotropic factor;
- Ed4 ADM uses mean radiance for each $1 \text{ Wm}^{-2}\text{sr}^{-1}$ Ψ bin, and interpolates between the Ψ bins. Third-order polynomial fits are used as backup;
- Will evaluate if more bins are needed.

$$\Psi(w, T_s, T_c, f, \epsilon_s, \epsilon_c) = (1 - f)\epsilon_s B(T_s) + \sum_{j=1}^2 \left[\epsilon_s B(T_s)(1 - \epsilon_{c_j}) + \epsilon_{c_j} B(T_{c_j}) \right] f_j$$

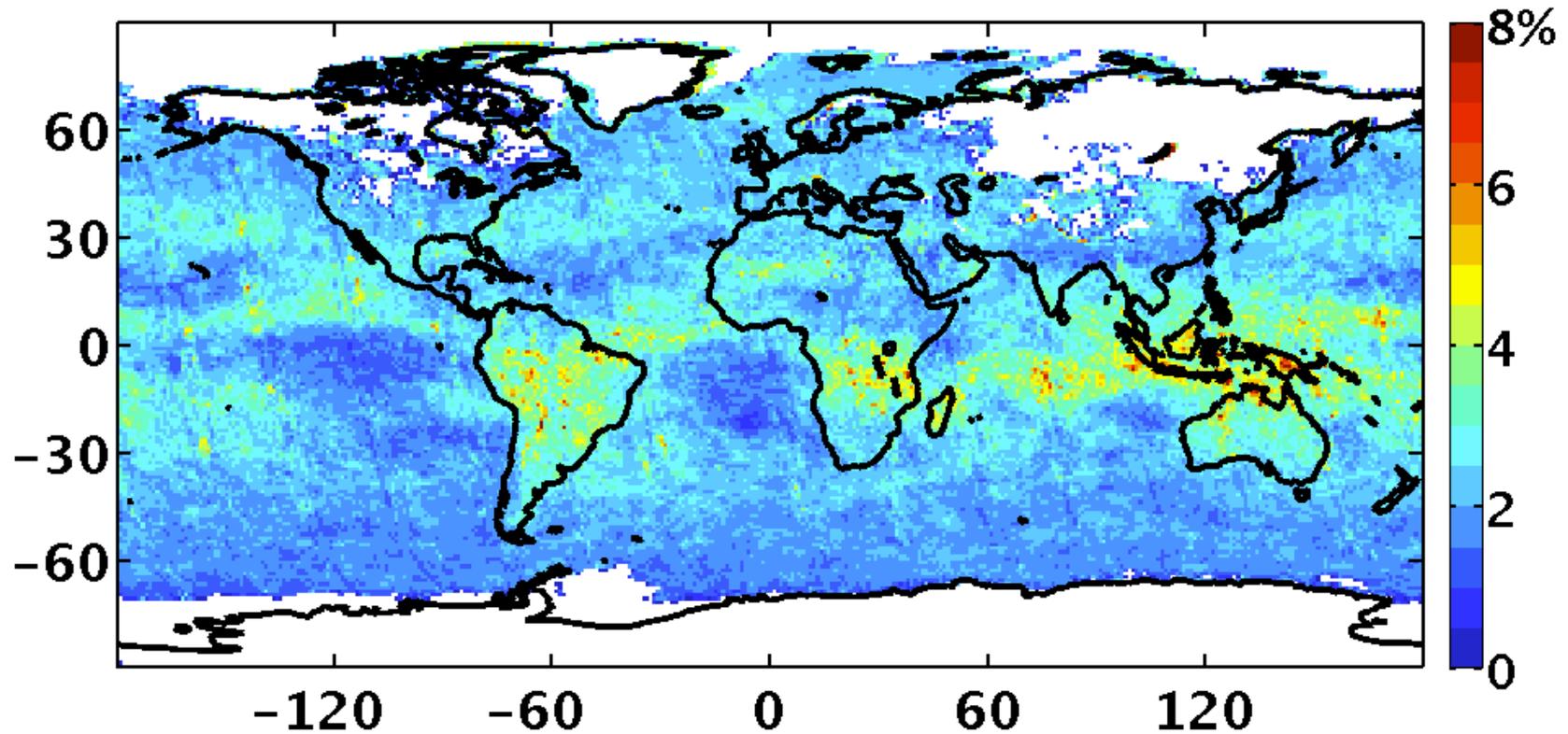
LW RMS error comparison between Ed2ADM and Ed4ADM: Jan 2001 daytime Terra

200101: Terra cld day ocn/Ind/des Ed4ADM: RMS=3.9%



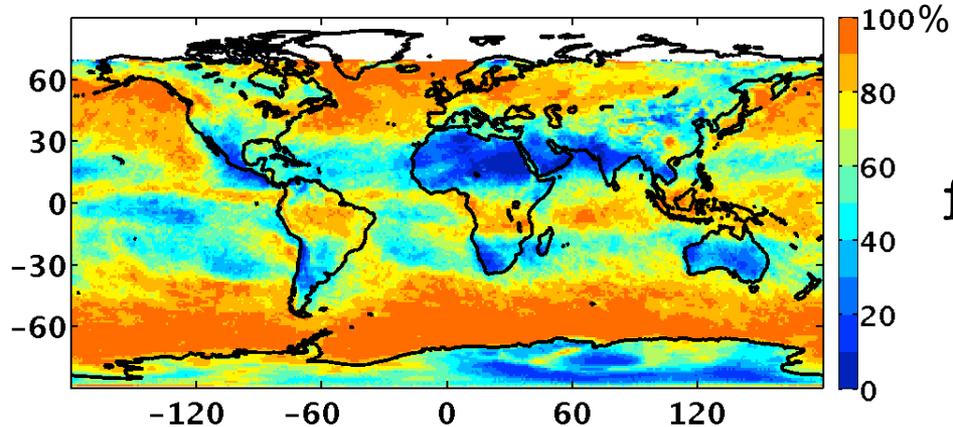
LW RMS error comparison between Ed2ADM and Ed4ADM: Jan 2001 nighttime Terra

200101: Terra cld nit ocn/Ind/des Ed4ADM: RMS=2.5%

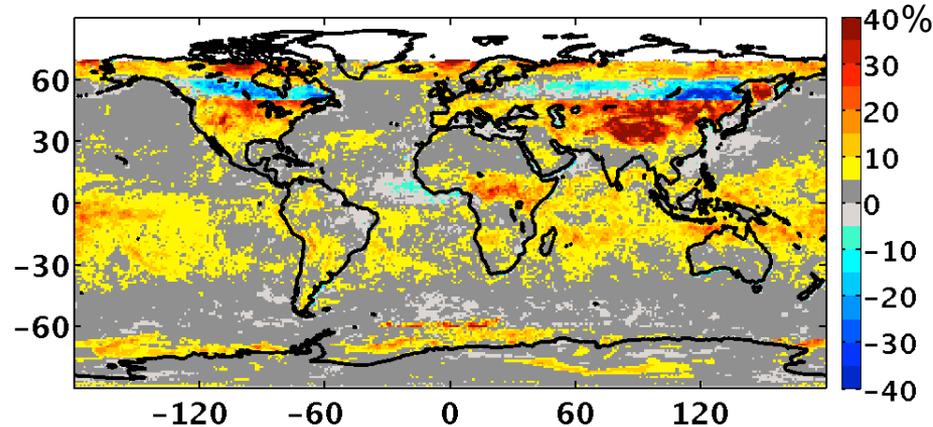


Daytime Cloud property difference between Ed3 and Ed4

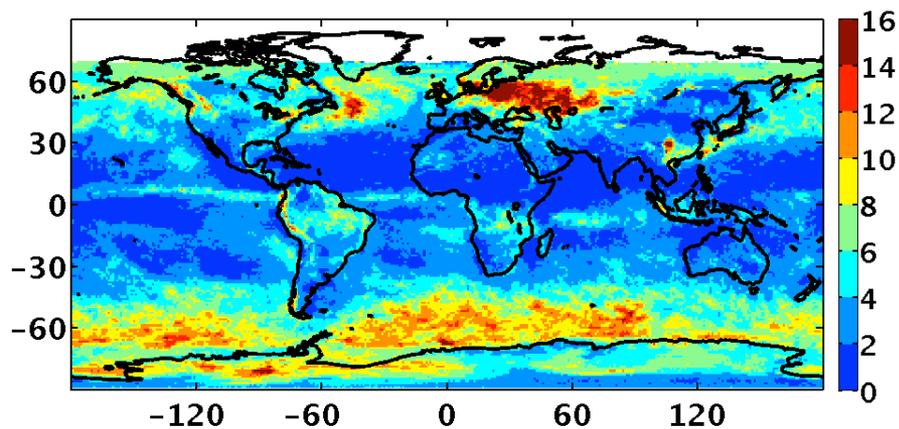
200201:Terra FM1 Cloud fraction Ed4: mean $f=67.8\%$



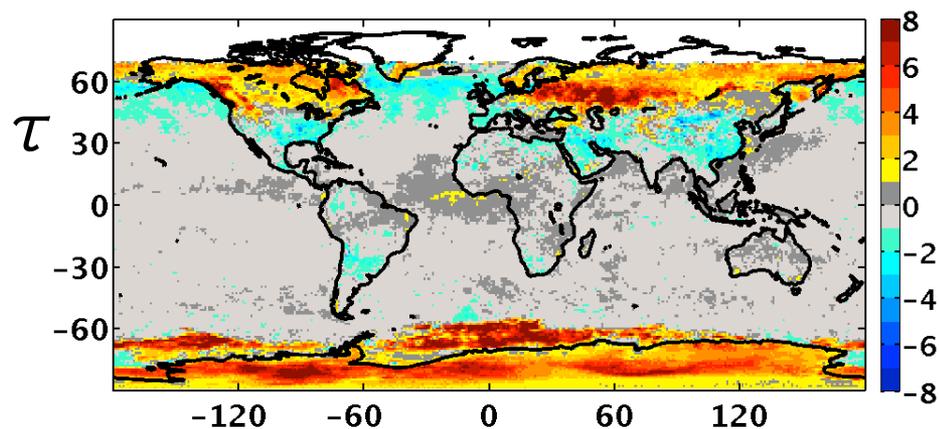
200201:Terra FM1 Cloud fraction diff (Ed4-Ed3): $\Delta f=4.7\%$



200201:Terra FM1 Cloud τ for Ed4: mean $\tau=4.7$

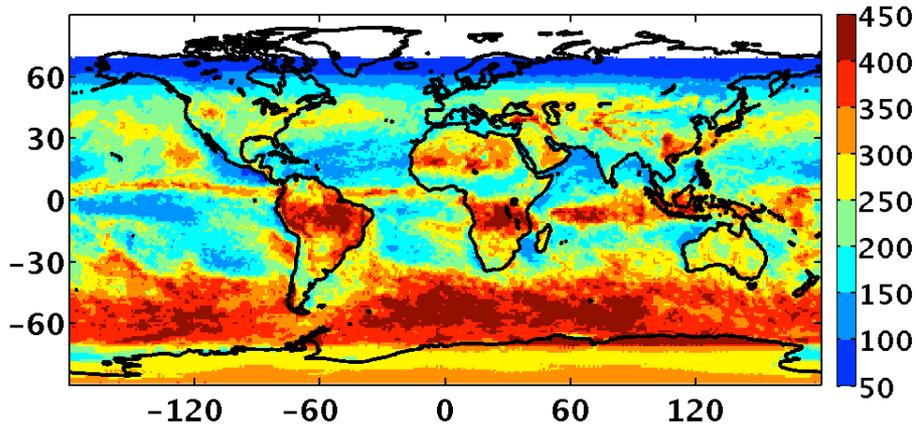


200201:Terra FM1 Cloud τ diff (Ed4-Ed3): $\Delta\tau=0.6$

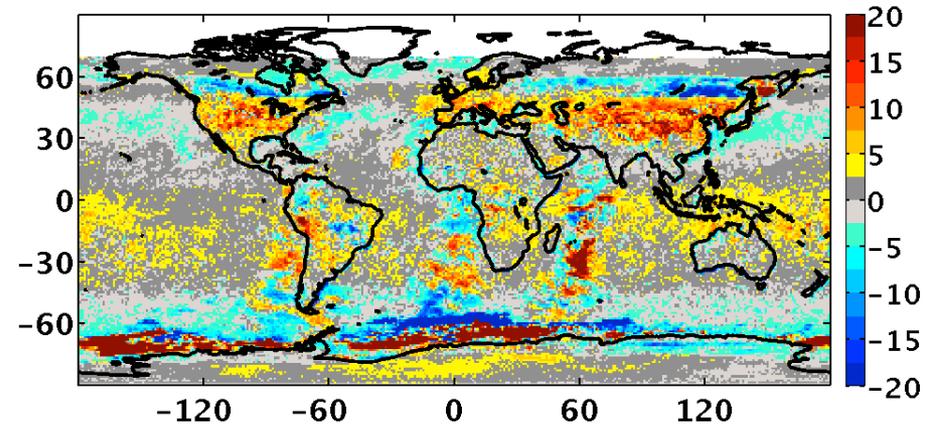


SW flux change between Ed3 and Ed4

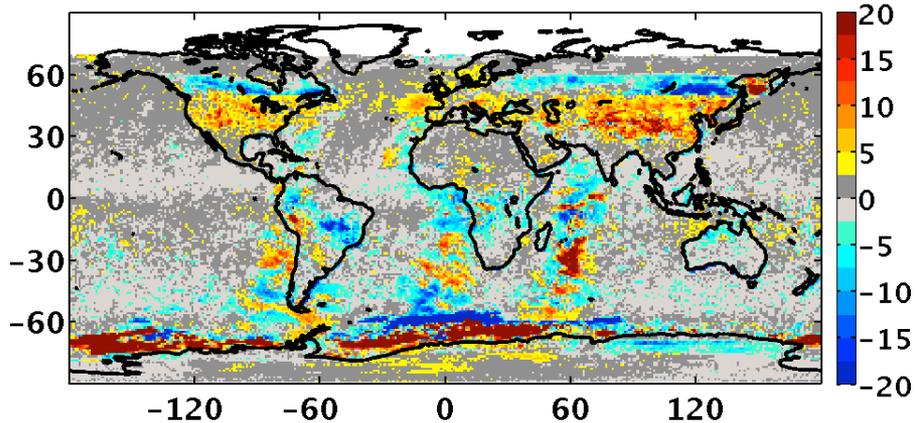
200201:Terra FM1 SW flux Ed4: mean SW=253.2Wm⁻²



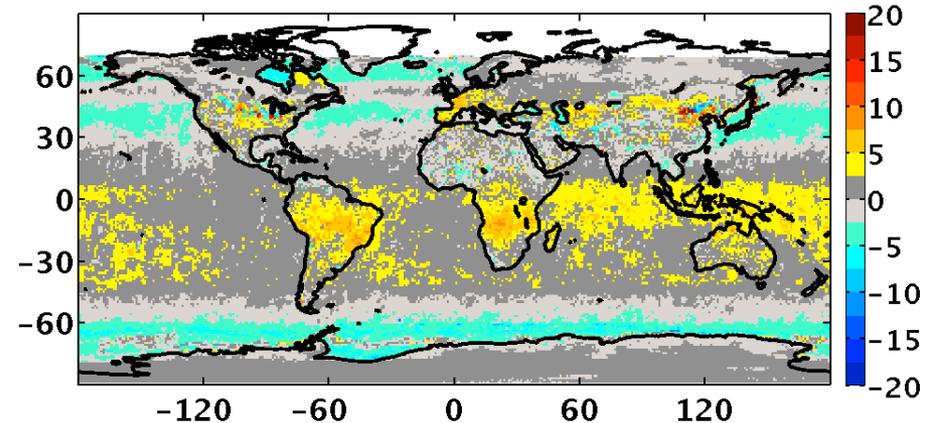
200201:Terra FM1 SW flux Diff (Ed4-Ed3): Δ SW=1.0Wm⁻²



200201:Terra FM1 SW Diff (Ed4S/Ed2A-Ed3S/Ed2A): Δ SW=0.3Wm⁻²



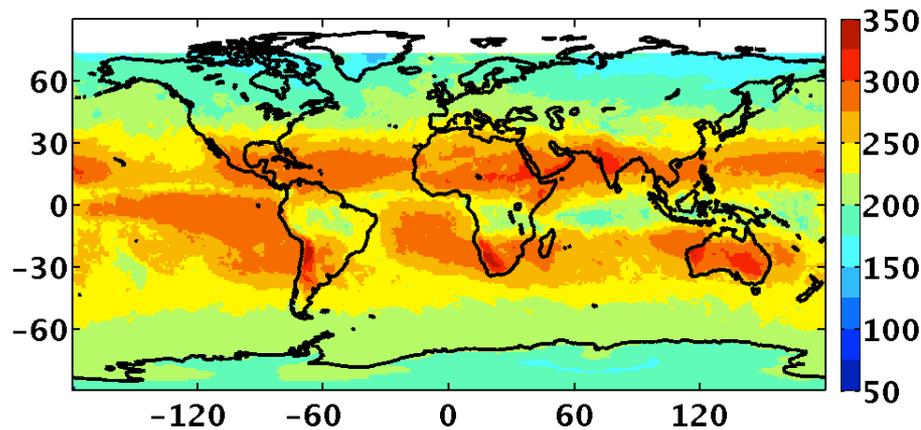
200201:Terra FM1 SW Diff (Ed4S/Ed4A-Ed4S/Ed2A): Δ SW=0.7Wm⁻²



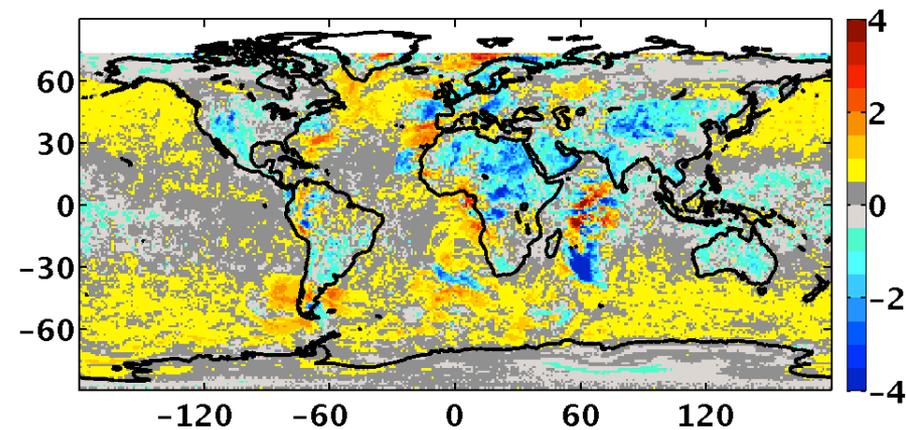
Ed4ADM: clear land, cloudy ocean, cloudy land, and sea ice

Daytime LW flux change between Ed3 and Ed4

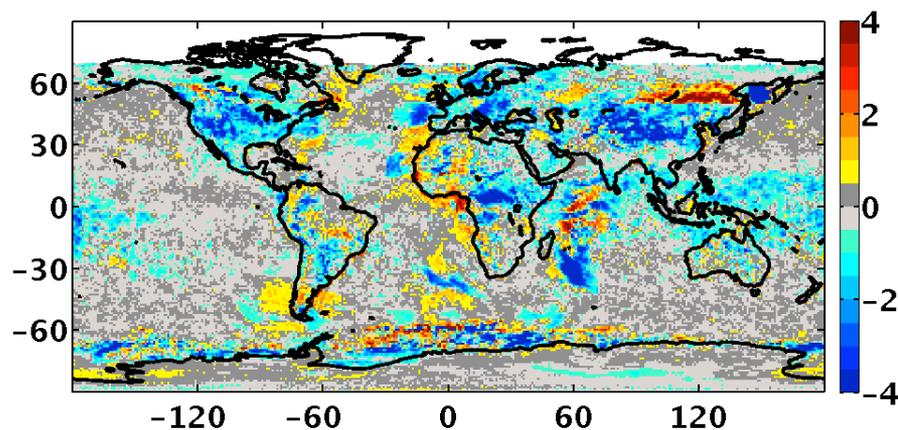
200201: Terra FM1(Ed4S/Ed4A) day: LW=241.1Wm⁻²



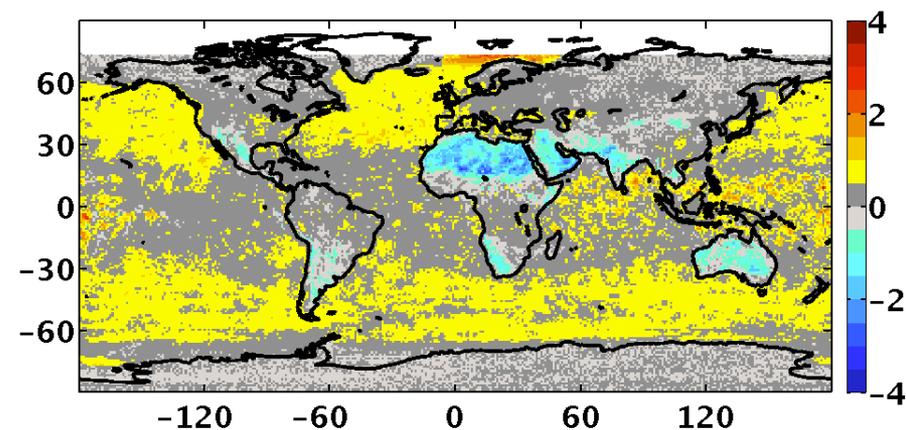
200201: Terra FM1(Ed4-Ed3) day: ΔLW=0.1Wm⁻²



200201:Terra FM1 ΔLW (Ed4S/Ed2A-Ed3S/Ed2A) rd%: ΔLW=-0.3Wm⁻²



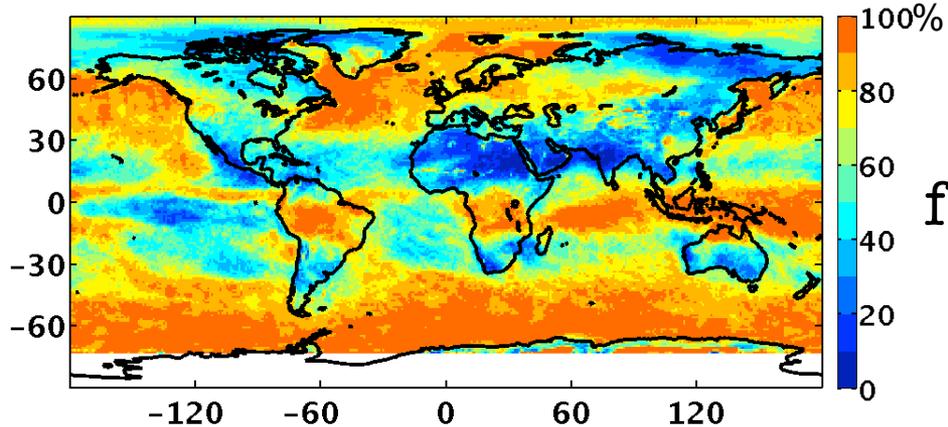
200201: Terra FM1 (Ed4S/Ed4A-Ed4S/Ed2A: ΔLW=0.3Wm⁻²



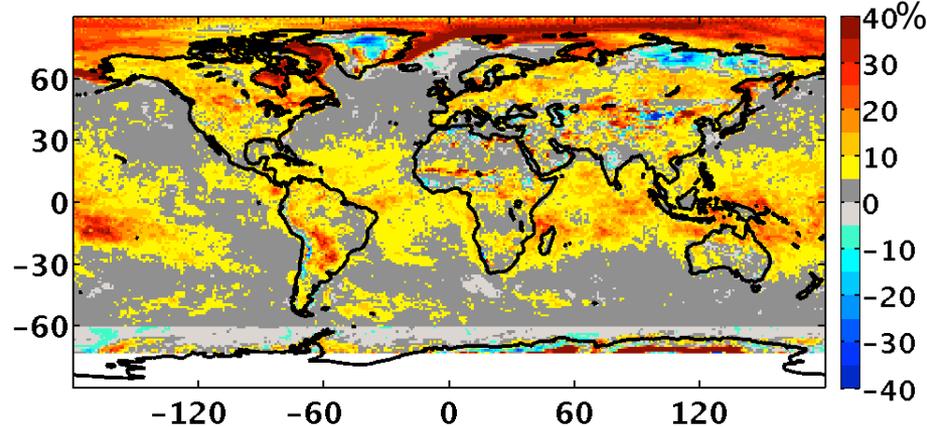
Ed4ADM: clear ocean/land/desert, cloudy ocean/land/desert

Nighttime Cloud property difference between Ed3 and Ed4

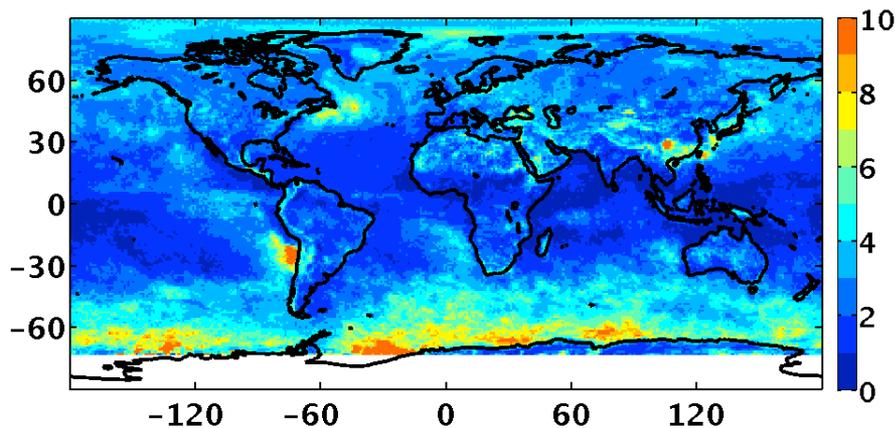
200201:Terra FM1 Cloud fraction Ed4: mean $f=67.7\%$



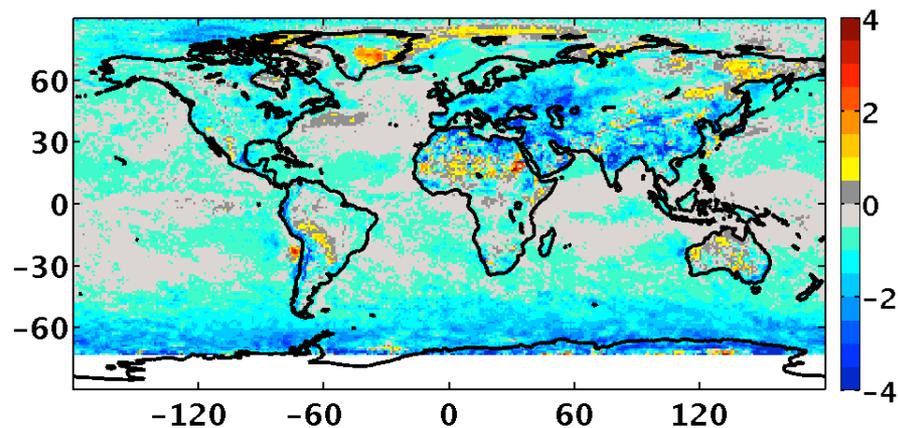
200201:Terra FM1 Cloud fraction diff (Ed4-Ed3): $\Delta f=7.4\%$



200201:Terra FM1 Cloud τ for Ed4: mean $\tau=3.0$

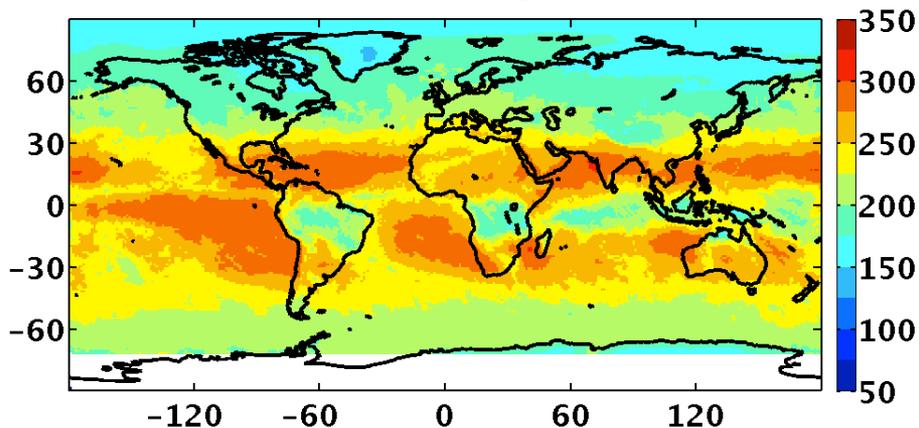


200201:Terra FM1 Cloud τ diff (Ed4-Ed3): $\Delta\tau=-0.8$

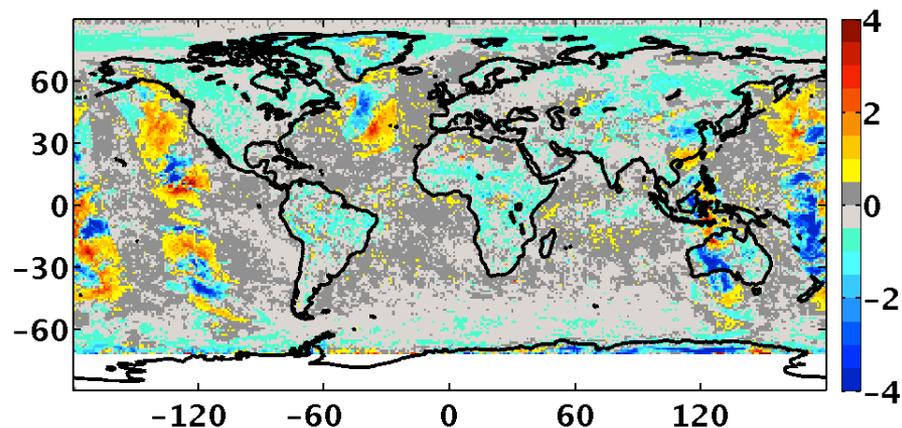


Nighttime LW flux change between Ed3 and Ed4

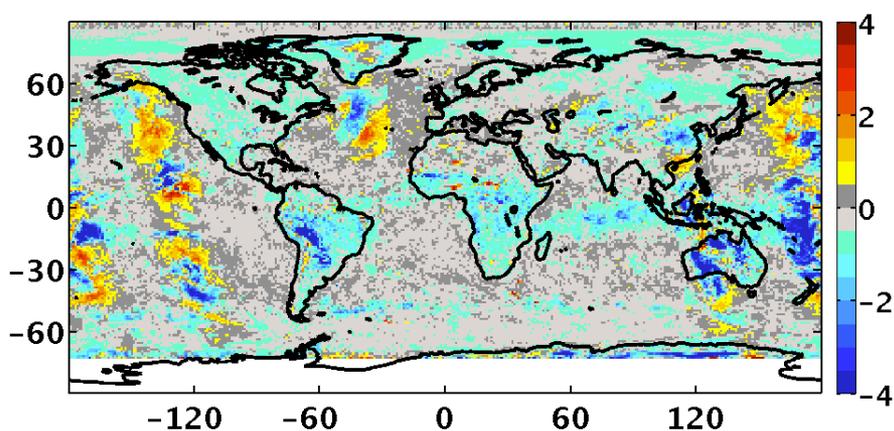
200201: Terra FM1(Ed4S/Ed4A) night: LW=235.3Wm⁻²



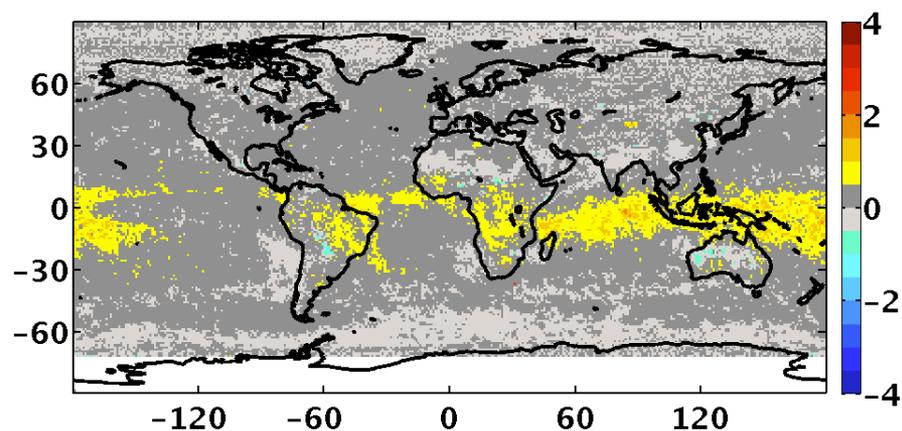
200201: Terra FM1(Ed4-Ed3) night: ΔLW=-0.1Wm⁻²



200201:Terra FM1 ΔLW (Ed4S/Ed2A-Ed3S/Ed2A): ΔLW=-0.4Wm⁻²



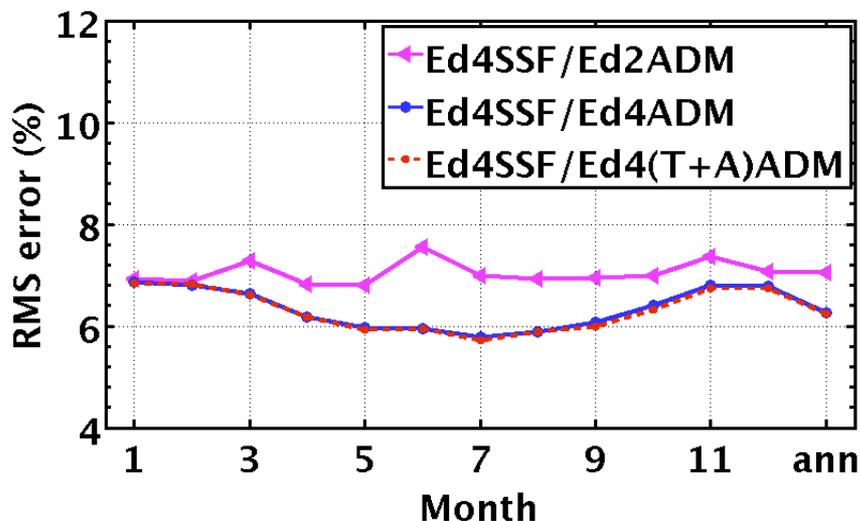
200201: Terra FM1(Ed4S/Ed4A-Ed4S/Ed2A) nit: ΔLW=0.2Wm⁻²



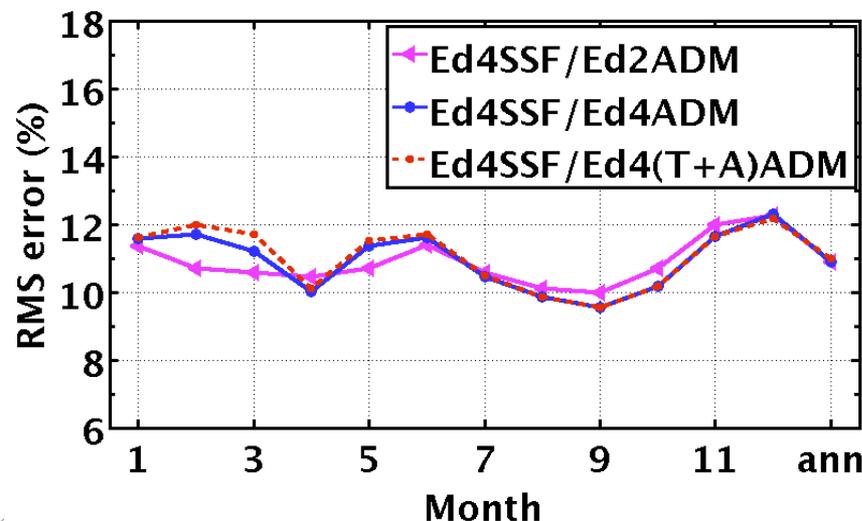
Ed4ADM: clear ocean/land/desert, cloudy ocean/land/desert

Terra ADM vs. combined Terra+Aqua ADM

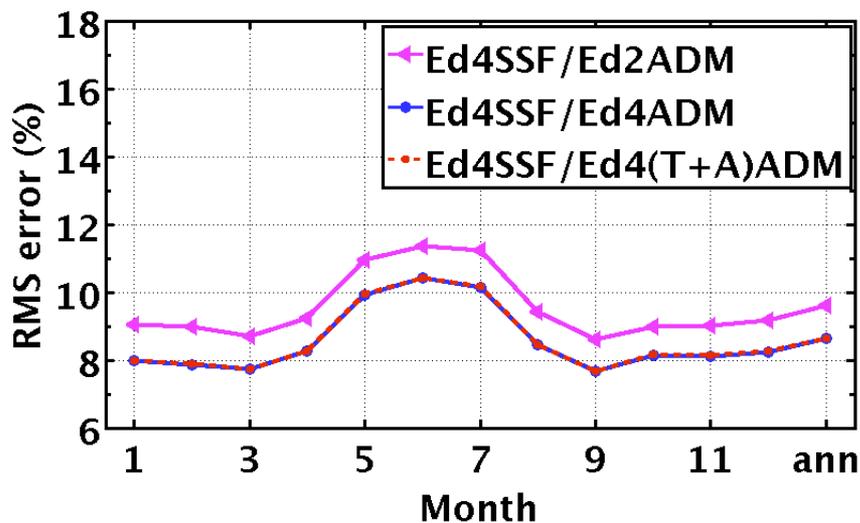
Clear Land RMS error for Terra FM1 2002



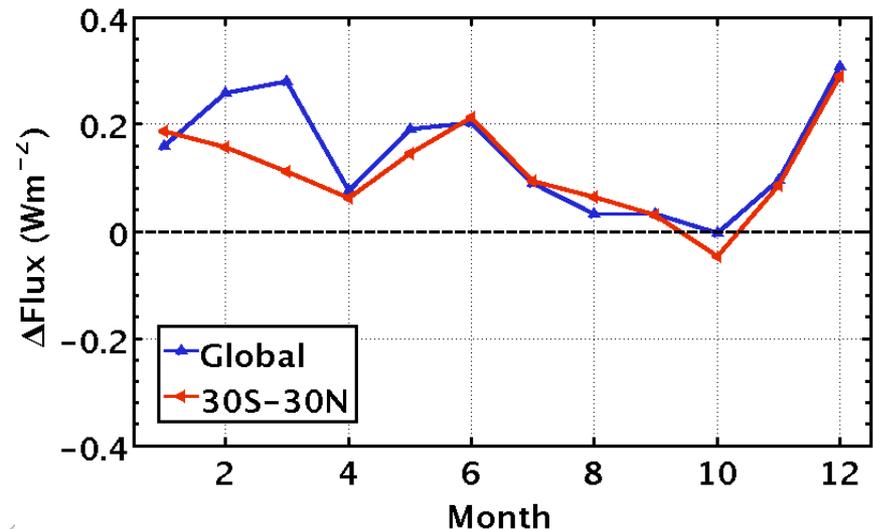
Cloudy Land RMS error for Terra FM1 2002



Cloudy Ocean RMS error for Terra FM1 2002

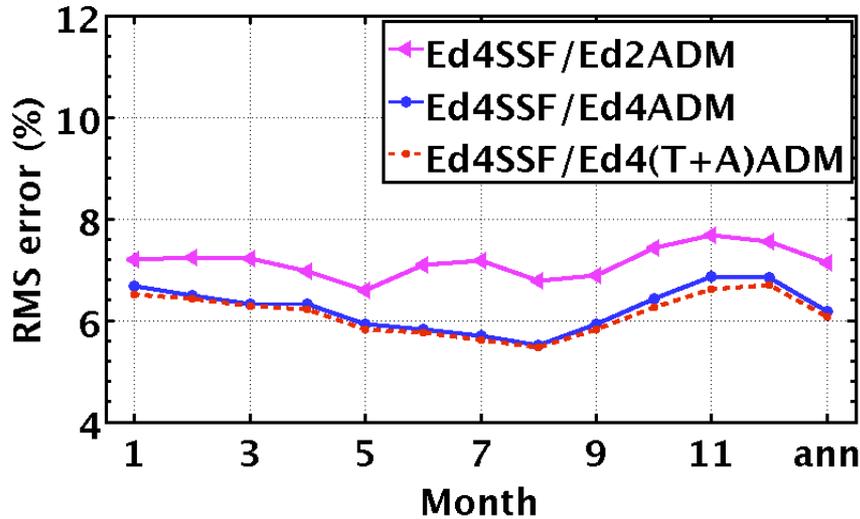


Terra+AquaADM-TerraADM for Terra FM1 2002

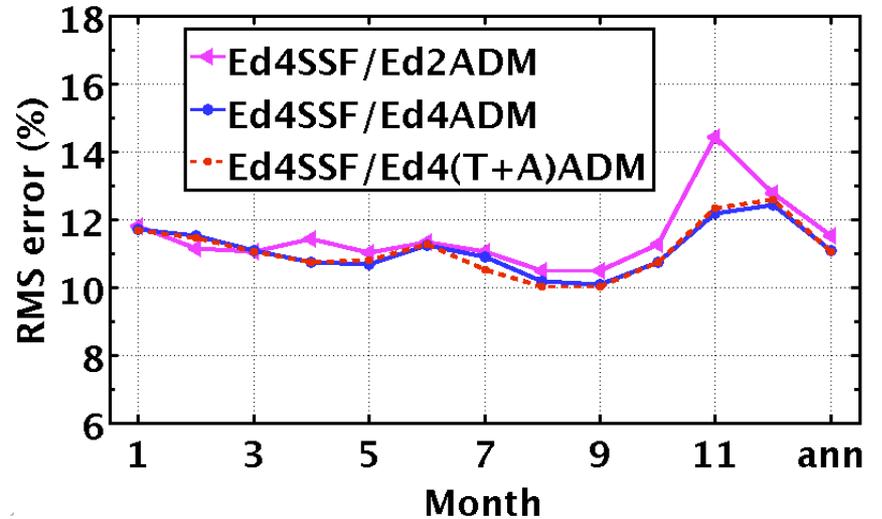


Aqua ADM vs. combined Terra+Aqua ADM

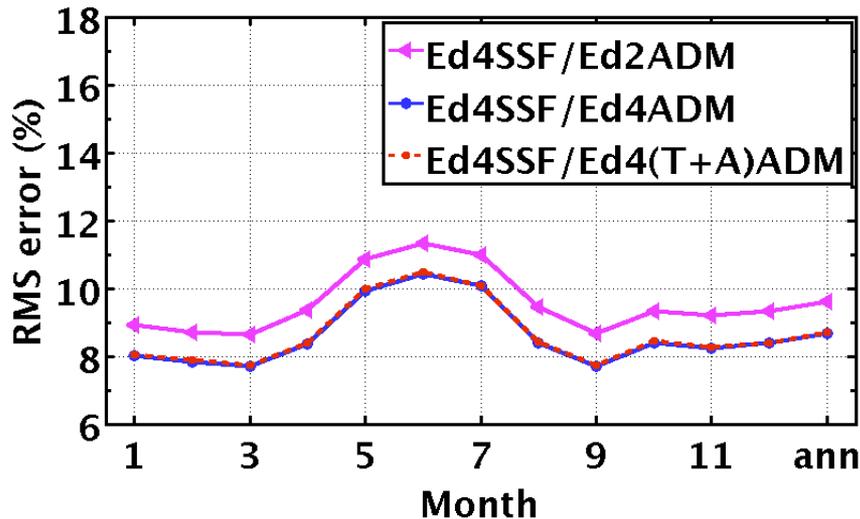
Clear Land RMS error for Aqua FM4 2004



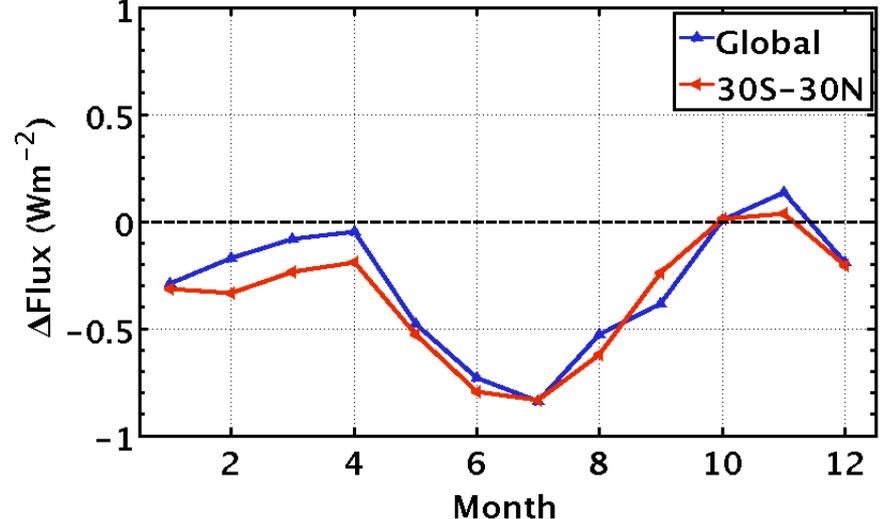
Cloudy Land RMS error for Aqua FM4 2004



Cloudy Ocean RMS error for Aqua FM4 2004



Terra+AquaADM-AquaADM for Aqua FM4 2002



Direct integration for SW flux

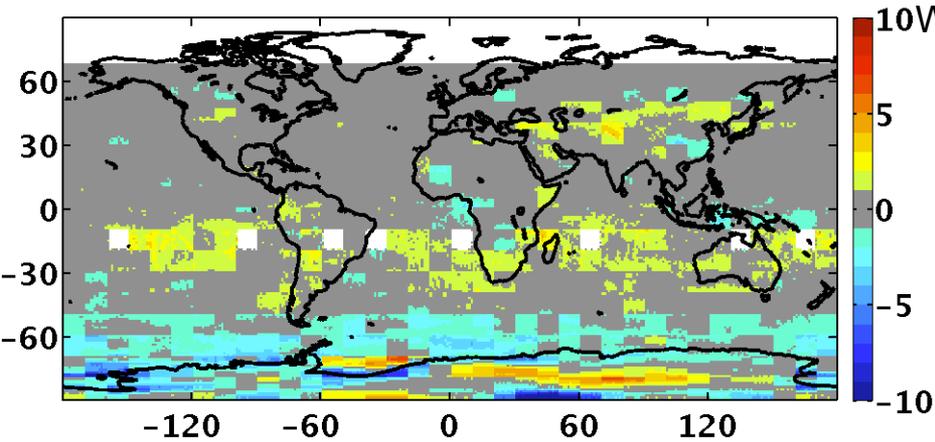
- Use observed (I_o) and ADM-predicted (\hat{I}) radiances to construct two sets of regional ($10^\circ \times 10^\circ$) all-sky ADMs for each season

$$F(\theta_0) = \frac{\pi I_o(\theta_0, \theta, \phi)}{R(\theta_0, \theta, \phi)} \quad R(\theta_0, \theta, \phi) = \frac{\pi \hat{I}(\theta_0, \theta, \phi)}{\hat{F}(\theta_0)}$$

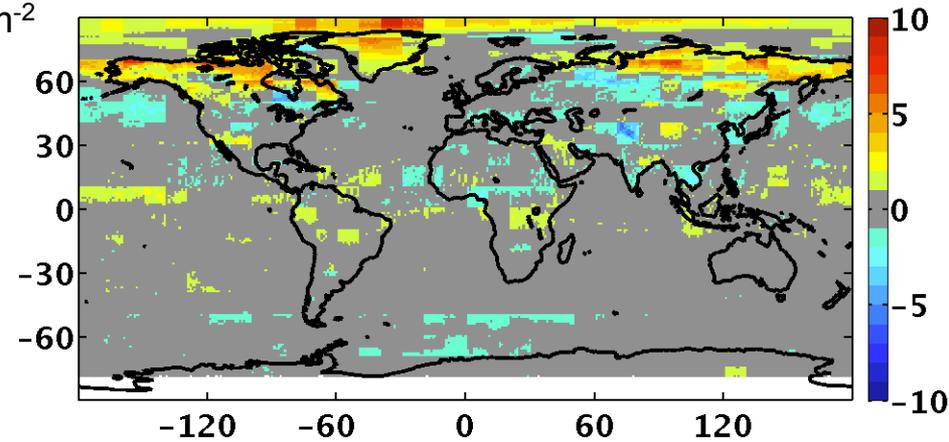
- Both sets of regional all-sky ADMs have the same sampling
- Compare fluxes derived from these two sets of ADMs

Direct integration flux error for 2002 Terra FM1 (flux from predicted radiance ADM - flux from observed radiance ADM)

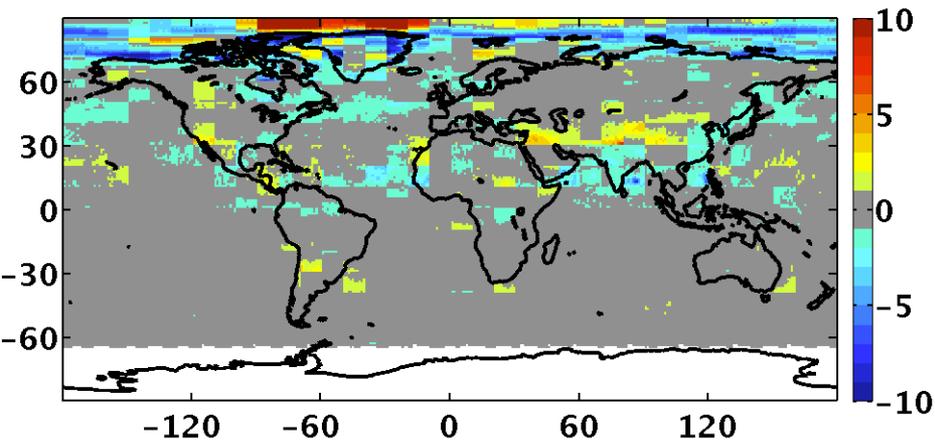
DI flux difference for Jan. 2002 FM1 Terra ADM



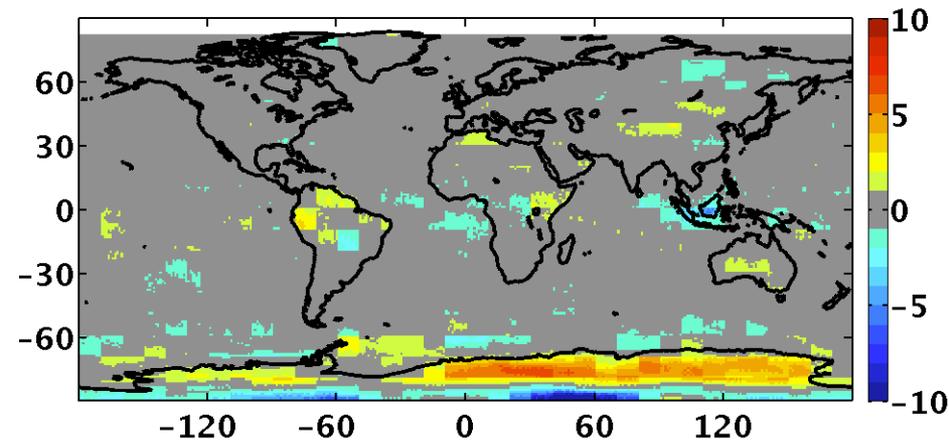
DI flux difference for Apr. 2002 FM1 Terra ADM



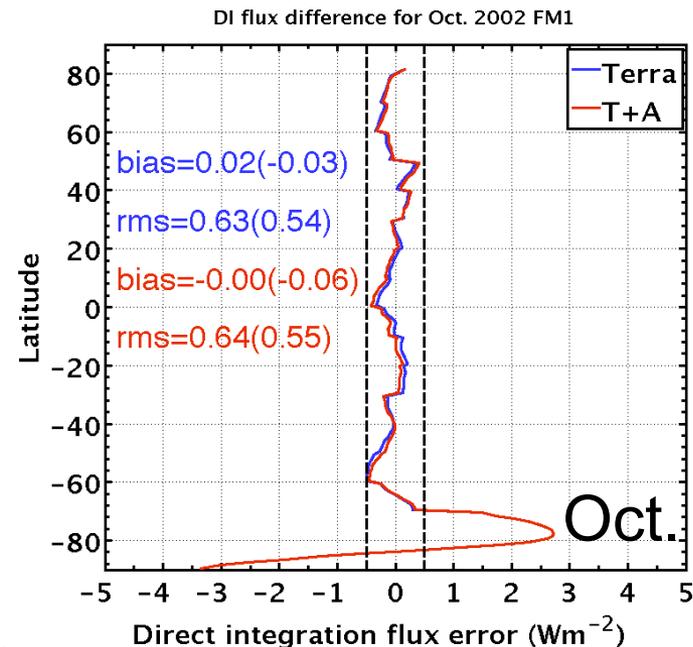
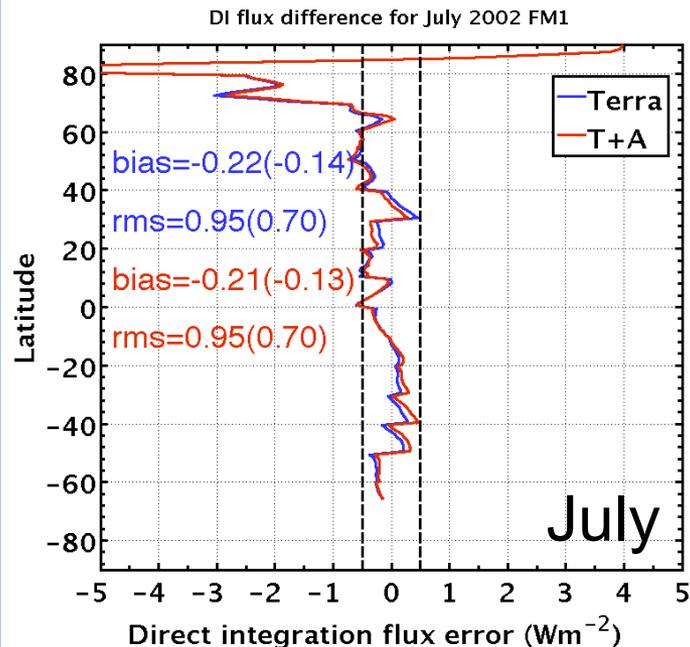
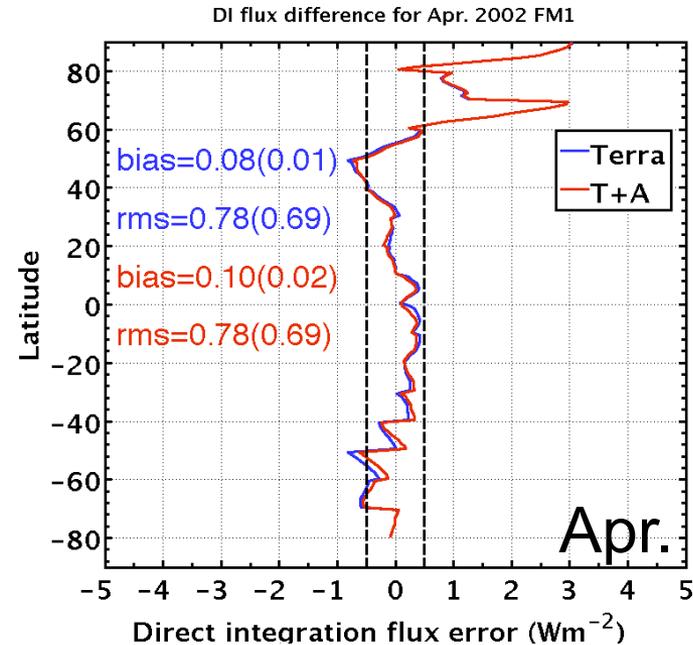
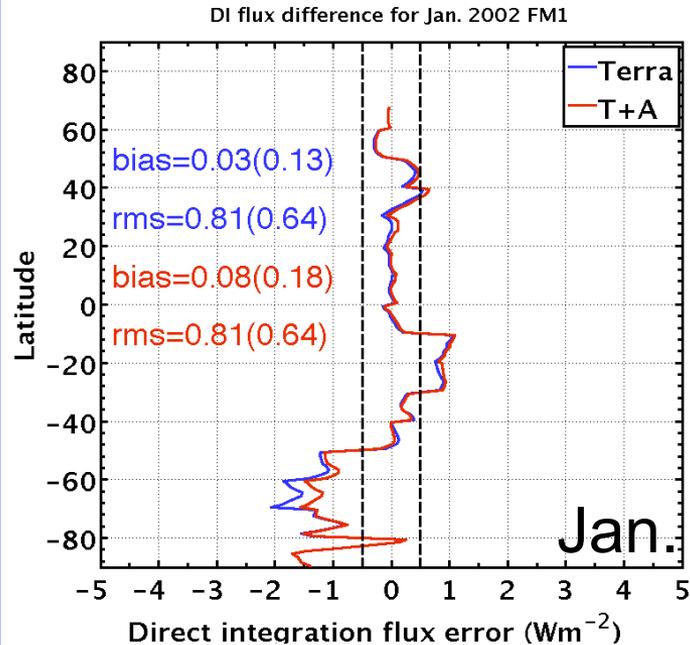
DI flux difference for July 2002 FM1 Terra ADM



DI flux difference for Oct. 2002 FM1 Terra ADM



Zonal mean flux error for 2002 Terra FM1



Summary

- We have worked through most scene types and have seen some improvement in the new Ed4 ADMs
- Ed4 cloud algorithm produces higher cloud fraction and more liquid clouds than Ed2 cloud algorithm
- Initial assessment indicates monthly global mean instantaneous SW flux will increase ($\sim 1.0 \text{ Wm}^{-2}$) due to changes in cloud properties and ADMs. Changes in LW flux are small ($\sim 0.1 \text{ Wm}^{-2}$)
- Combined Terra/Aqua ADMs (clear land, cloudy land, cloudy ocean) increase the monthly global mean fluxes from Terra (up to 0.3 Wm^{-2}), but decrease the monthly global mean fluxes from Aqua (up to 0.8 Wm^{-2}).
- Direct integration of SW indicates that zonal mean flux error is less than 0.5 Wm^{-2} over most none-polar regions.